The Petroleum Engineer

ALL DIVISIONS

• EXPLORATION, DRILLING and PRODUCTION
• REFINING and GAS PROCESSING
• OIL and GAS PIPELINING

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THE MIRACLE VALVE LUBRICANT
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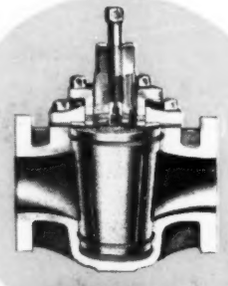
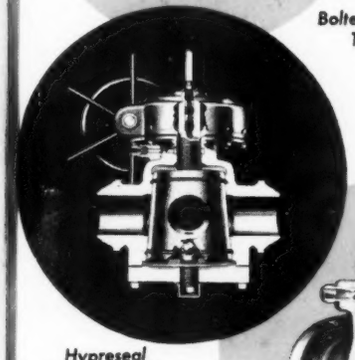
Establishes Amazing Performance Records

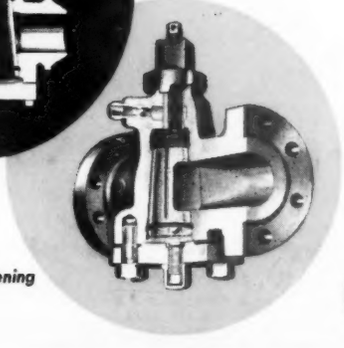


Bolted Gland Type

Since the introduction of Rockwell Hypermatic lubricant six months ago, thousands of operators of Nordstrom valves have had an opportunity to use it. Comparative tests prove tremendous savings in maintenance time. Operation records show increased efficiency, greatest ease in opening and closing the valves—and most important, full *automatic* lubrication. If you have not changed to Hypermatic, do so at once—you'll note a tremendous improvement. Hypermatic adds to Nordstrom valves now in use a vastly improved principle of lubrication that further reduces your valve maintenance costs and automatically prevents leakage.



Hypreseal Round Opening



Hypreseal Rectangular Opening

Nordstrom Valves

Nordstrom Valve Division — ROCKWELL MANUFACTURING CO.
400 North Lexington Avenue, Pittsburgh 8, Pa.
District Offices in all principal cities

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3 Methods of preventing evaporation losses

1. ***PRESSURE STORAGE***—This method of reducing evaporation losses makes use of storage tanks that are able to withstand the changes of pressure developed under storage conditions. As long as the pressure in the tank does not exceed the relief valve setting, no vapor will escape and there will be no evaporation loss.

We fabricate and erect four types of pressure storage tanks—Hemispheroids, Hortonspheroids, Hortonspheres and cylindrical pressure tanks.

Hemispheroids are built for working pressures of 2½ lbs. in capacities up to 30,000 bbls. and 5 lbs. per sq. in. for capacities up to 7,500 bbls. The range of working pressures for *Hortonspheroids* is from 2½ to 100 lbs. for capacities from 2,000 to 40,000 bbls. and from 2½ to 20 lbs. for noded spheroids from 20,000 to 120,000 bbls.

Hortonspheres are used for storing and handling butane, volatile refinery stocks, and the more volatile grades of natural gasoline. They are built in standard capacities up to 25,000 lbs. for pressures up to 50 lbs. per sq. in. and in smaller capacities for pressures as high as 200 lbs.

Cylindrical pressure tanks are recommended for storing highly volatile hydrocarbons like propane and are built for working pressures as high as 250 lbs. per sq. in.

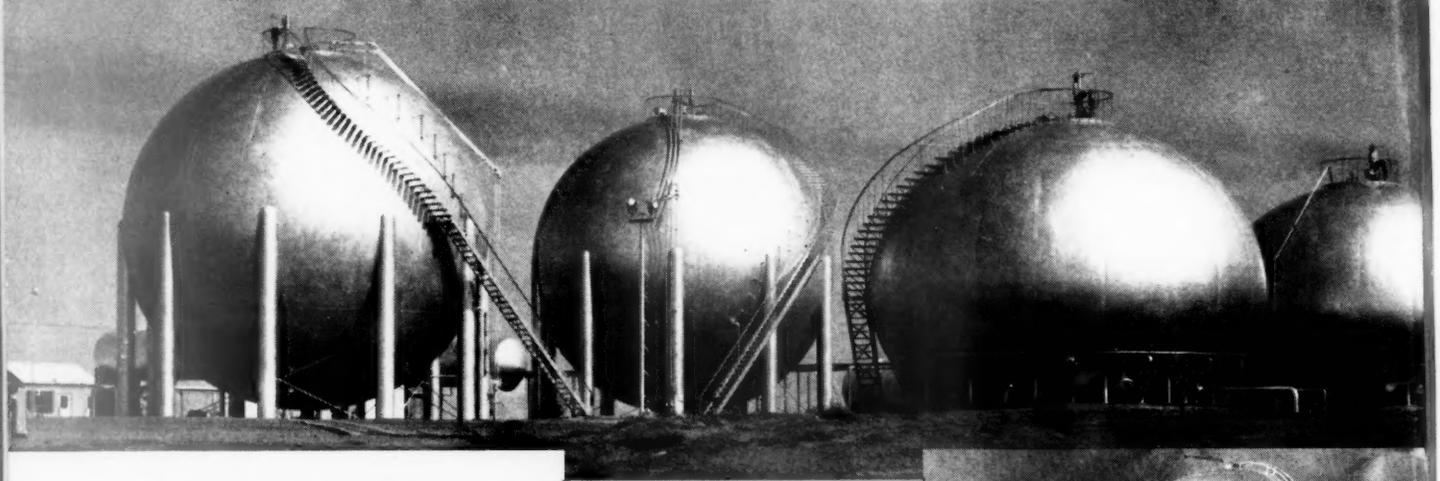
2. ***ELIMINATION OF VAPOR SPACE***—The elimination of the vapor space in a flat-bottom storage tank is accomplished by installing a Horton Floating Roof on the tank. Since it floats directly on the liquid, there is no air-vapor mixture under the roof. As a result, evaporation losses are decreased, the fire hazard is reduced and there is less corrosion on the underside of the roof.

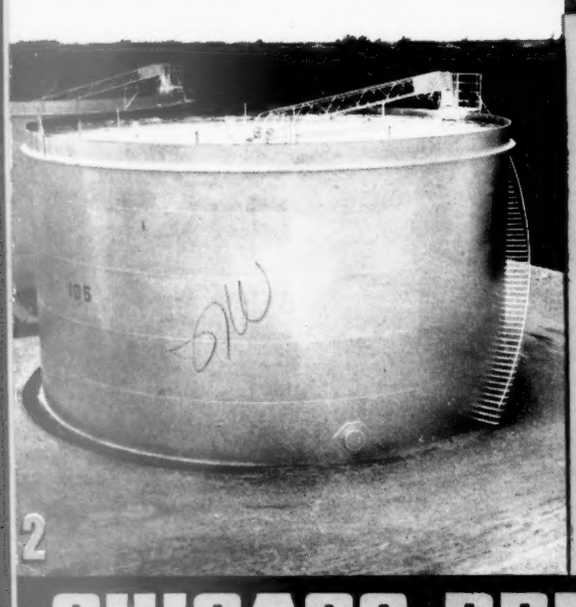
Horton Floating Roofs are available in three designs . . . DOUBLE-DECK, PONTOON, and PAN.

3. ***TEMPORARY VAPOR STORAGE***—This method provi facilities for storing temporarily the additional vapor volu caused by breathing or unbalanced pumping. Horton Vapordo Roofs, Vaporspheres, and Lifter Roofs are used for this purp

Vapordome Roofs and Lifter Roofs are installed directly flat-bottom tanks to serve one or more tanks. The Vaporsph is a separate vapor storage unit interconnected with one more tanks.

There are bulletins available which describe the three methods and the various Horton tanks in more detail. Write our nearest office for them

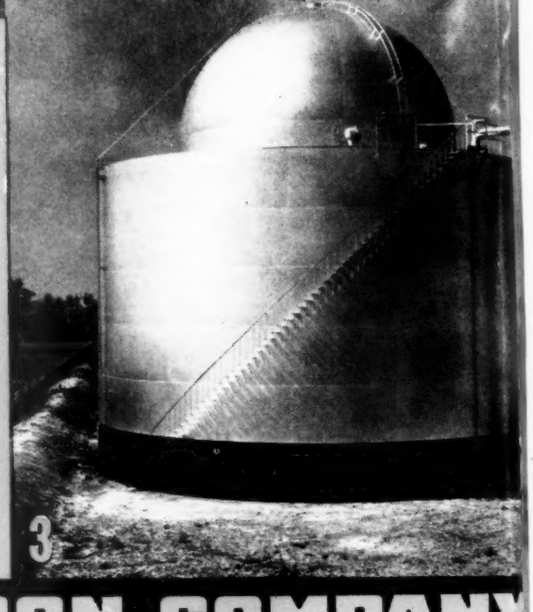




Above: Two Hortonspheres and two Hortonspheroids used for storing volatile hydrocarbons at a cycling plant in Oklahoma.

Left: Gasoline storage tank equipped with a Horton Double-Deck Floating Roof at a pipe line terminal in Florida. This view shows very clearly that the roof floats on the liquid in the tank.

Right: 20,000-bbl. gasoline storage tank equipped with a Horton Vapordome Roof at a transport terminal in Texas.



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The Petroleum Engineer

ALL DIVISIONS

- Exploration Drilling and Production
- Refining and Gas Processing
- Oil and Gas Pipelining

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Editorial

It is perhaps well to remind our readers that this is the Reference Annual Number of *The Petroleum Engineer*. As such, it is devoted exclusively to a selected list of articles from the best in the petroleum literature published during the last twelve months. Our editors find that the matter of selection becomes more difficult with each passing year. Advancements in the different branches of the petroleum industry range from extremely practical to the highly technical. As might be expected, they are quite diversified and cover a broad field. Evidence of the pace of progress in the development of processes and practices is the voluminous output of petroleum literature in recent years. This is not surprising in view of the fact that many of the operations of the petroleum industry are becoming highly specialized. Such specialization demands that great care and consideration be exercised in the choice articles for their reference value.

Because of the fact that the petroleum literature is expanding at an inordinately rapid rate, the number of reference articles that can be included each year becomes an increasingly smaller proportion of the total articles available for publication. Nevertheless, it should be repeated that all articles have been selected for inclusion in this issue principally because of their potential reference value to our readers, particularly those that do not have access to papers of leading technical societies, associations, or other groups.

An effort has been made to include as many articles as possible containing information of the type that will foster greater economy and efficiency, two factors that have been given great weight in selecting the articles for this issue. In so doing, readers in the operating branches of the industry, it is hoped, will be aided in keeping abreast of developments in the branch of the industry in which they are interested.

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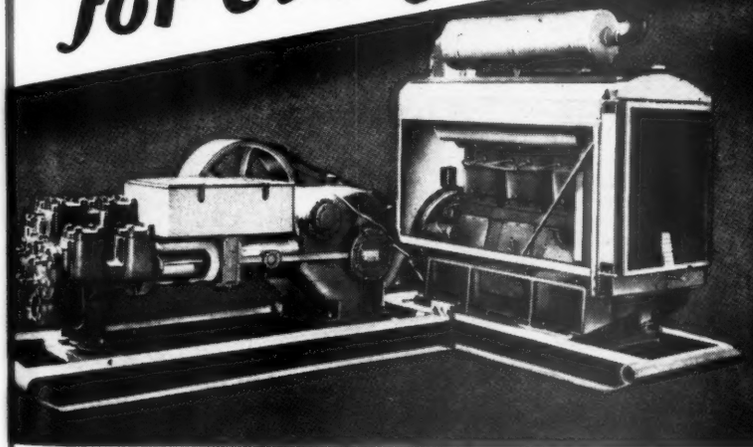

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XUM

DATA ON IMPORTANT OIL FIELDS OF THE UNITED STATES

(Continued)

No.	Year discovered	Field	County	Producing formation	Gravity °API	Productive acres	Estimated Average thickness (feet)
				TEXAS (Contd.)			
		R. R. Com. Dist 7B					
156	1902		Brown	Pen, Miss, Ord	27.0-42.0	8,670	—
157	1916		Callahan	Per to Ord	26.0-40.0	6,410	—
158	1902		Coleman	Per, Pen, Ord	28.0-43.0	10,080	—
159	1917		Eastland, Erath	Pen, Miss, Ord	33.0-42.0	19,480	—
160	1928		Fisher	Per, Pen	37.0-40.0	4,785	—
161	1926		Jones	Per, Pen	35.0-43.0	16,085	—
162	1910		Shackelford	Per, Ord	36.0-45.0	14,895	—
163	1916		Stephens	Per to Ord	36.0-43.0	49,620	—
164	1929		Taylor	Per, Pen	35.0-43.0	2,690	—
165	1924		Throckmorton	Pen, Miss	34.0-41.0	2,700	—
		R. R. Com. Dist. 7C					
166	1941	Barnhart	Reagan	Ellenburger Dole; Ord	44.0	560	75
167	1923, 28	Big Lake and Big Lake Ord	Reagan	Queen, San Andres, Clear Fork, Ellenburger; Ord	37.0-44.0	5,000	60; 100
168	1925	McCamey	Upton, Crane	Grayburg, San Andres; Per	28.0	20,000	40
169	1940	Todd, Deep	Crockett	Strawn; Pen. Ellenburger; Ord.	42.0	2,000	88
170	—	World	Crockett	Grayburg, San Andres; Per	29.0	3,660	25
		R. R. Com. Dist. 8					
171	1940	Abell Ord	Pecos	Simpson, Ellenburger; Ord	42.0	3,348	30
172	1939	Cedar Lake	Gaines	San Andres; Per	33.0	2,320	160
173	1926	Cowden Crane	Crane	Whitehorse	28.0	1,819	10; 60
174	1930	Cowden (North)	Ector	San Andres, Clear Fork; Per	32.0	27,000	40; 200
175	1939	Cowden (North deep)	Ector	Clear Fork; Per	37.0	640	20; 40
176	1930	Cowden (South)	Ector	San Andres; Per	34.0	5,508	42; 225
177	1936	Eaves	Winkler	Yates, Seven Rivers; Per	26.0	920	20
178	1942	Embar Ellen	Andrews	Ellenburger; Ord	45.0	2,230	223; 85
179	1937	Emma	Andrews	San Andres; Per	34.0	1,900	25; 90
180	1936	Emperor	Winkler	Yates; Per	32.0	2,200	45
181	1932	Foster	Ector	San Andres; Per	34.0	20,000	42; 85
182	1930	Fuhrman Mascho	Andrews	San Andres; Per	30.0	11,800	20; 60
183	1942	Fullerton	Andrews	Clear Fork, Tubb; Per	43.0	40,000	100; 285
184	1944	Fullerton "8,500 ft"	Andrews	Devonian	40.0	2,000	125
185	1938	Garza	Garza	San Andres; Per	29.0	2,040	20
186	1934	Goldsmith	Ector	San Andres; Per	36.0	26,000	60
187	1934	Harper	Ector	San Andres; Per	36.0	4,500	20; 75
188	1936	Henderson	Winkler	Whitehorse, Holt	29.0	2,000	30; 100
189	1926	Hendrick	Winkler	Seven Rivers; Per	28.0	9,950	300
190	1926	Howard Glasscock	Howard, Glasscock	Yates, Seven Rivers, Grayburg, San Andres	27.0-41.0	15,000	25; 50
191	1926	Iatan, East Howard	Howard, Mitchell	Grayburg; Per	30.4	8,320	20; 200
192	1935	Johnson	Ector	San Andres; Per	34.0	7,500	25
193	1937	Jordan	Crane	San Andres; Per	32.0	7,500	20; 150
194	1928	Kermit	Winkler	Yates Sand; Per	27.0	11,520	40; 200
195	1930	Keystone Colby	Winkler	Whitehorse; Per	28.0-35.0	9,500	22; 170
196	1943	Keystone Ellen	Winkler	Ellenburger; Ord	43.0	—	750
197	1943	Keystone Holt	Winkler	Holt; Per	39.0	3,400	50
198	1935	Keystone Lime	Winkler	San Andres; Per	36.0	3,000	150
199	1944	Mabee	Martin, Andrews	Grayburg; Per	31.0	5,000	50
200	1926	McElroy	Andrews	Grayburg; Per	30.0	16,000	150
201	1934	Means	Crane, Upton	San Andres; Per	30.0	5,000	50
202	1929	Penwell	Ector	San Andres; Per	—	6,000	30; 100
203	1930	Sand Hills Tubb	Crane	Clear Fork; Per	35.0	10,000	40; 150
204	1927	Scarborough	Winkler	Yates Sand; Per	30.0	1,500	10; 75
205	1936	Seminole	Gaines	San Andres; Per	35.0	13,320	90; 175
206	1928	Shipley	Ward	Seven Rivers, Queen	35.0	5,560	60; 30
207	1936	Slaughter	Cochran, Hockley, Terry	San Andres; Per	32.0	82,000	32; 75
208	1929	Taylor-Link	Pecos	Yates, Queen, San Andres; Per	29.0	3,000	25
209	1928	Toborg	Pecos	Toborg, Trinity	19.0	3,200	15
210	1945	T.X.L. Devonian	Ector	Devonian	40.0	6,400	175
211	1945	T.X.L. Ellenburger	Ector	Ellenburger; Ord	43.0	5,000	200
212	1943	Union	Andrews	Clear Fork; Per	43.0	960	150
213	1927	Waddel	Crane	San Andres; Per	35.0	5,160	150
214	1929	Ward, North Estes	Ward, Winkler	Yates Sand; Per	34.5	16,990	40
215	1930	Ward (South)	Ward	Seven Rivers; Per	32.0	15,000	75
216	1936	Wasson (incl 66 & 72)	Gaines, Yokum	Clear Fork, San Andres; Per	34.0	62,000	250
217	1941	Welch	Dawson	San Andres; Per	33.0	1,800	45
218	1921	Westbrook	Mitchell	Clear Fork; Per	25.0	4,400	100
219	1925	Wheat	Loving	Delaware; Per	38.0	4,680	20
220	1926	Yates (incl Yates Smith Sand)	Pecos	San Andres, Yates; Per	30.0	23,900	200
		R. R. Com. Dist. 9					
221	1911	Archer Co. (total)	Archer		36.0-44.0	55,770	—
222	1939	Hull-Silk-Sikes	Archer	Strawn; Pen	44.0	7,500	100

From The Petroleum Data Book, Second Edition, which carries 750 pages of information on the petroleum industry.

DATA ON IMPORTANT OIL FIELDS OF THE UNITED STATES

(Continued)

No.	Year discovered	Field	County	Producing formation	Gravity °API	Productive acres	Estimated Average thickness (feet)
		R. R. Com. Dist. 3 (Contd.)		**TEXAS (Contd.)**			
34	1903, 34	Batson (Shallow and Deep)	Hardin	Cap, Mio; Olig	24.0-38.0	650	30
35	1934	Bay City	Matagorda	Frio; Olig	35.5	1,240	25
36	1942	Bay City, North	Matagorda	Frio; Olig	35.0	800	20
37	1922	Big Creek	Fort Bend	Mio, Olig	22.0-42.0	300	15
38	1919	Blue Ridge	Fort Bend	Mio. Frio; Olig	21.0-38.0	500	30
39	1925	Boling	Fort Bend, Wharton	Cap Rock Frio; Mio, Olig	19.0-33.0	2,000	20
40	1938	Cedar Point	Chambers	Frio; Olig, Mio	28.0-38.0	800	40
41	1938	Clear Lake	Harris	Frio, Cockfield	26.0-31.0	2,100	30
42	1931	Conroe	Montgomery	Cockfield; Eoc	35.0-40.0	18,000	30
43	1937	Cotton Lake, South	Chambers	Frio; Olig	33.0	500	20
44	1934	Dickenson	Galveston	Frio; Olig	37.0	2,700	20
45	1940	Dyersdale	Harris	Frio; Olig	22.0	1,200	15
46	1929, 39	Esperson (incl South)	Liberty	Mio, Olig. Yegua, Cook Mt; Eoc	21.0-41.0	1,600	20
47	1938	Fairbanks	Harris	Yegua, Catahoula, Marg	39.0	4,000	20
48	1927	Fannett	Jefferson	Frio; Olig, Mio	26.0-38.0	1,200	20; 200
49	1940	Fig Ridge	Chambers	Frio; Olig	32.0	2,000	55
50	1935	Gillock	Galveston	Frio; Olig	37.0	2,250	15
51	1907	Goose Creek	Harris	Plio, Mio, Olig	20.0-36.0	900	10
52	1936	Hamman	Matagorda	Frio; Olig	37.0	1,100	20
53	1929, 34	Hankamer (New and Old)	Liberty	Frio; Olig, Mio	18.0-32.0	690	20
54	1935	Hardin	Liberty	Frio; Olig. Yegua; Eoc	37.0-56.0	2,750	10
55	1934	Hastings	Brazoria	Frio; Olig	30.0	5,800	300
56	1922	High Island	Galveston	Mio	31.0	800	40
57	1918	Hull	Liberty	Cap; Mio, Olig. Yegua, Cook Mt; Eoc	17.0-39.0	875	60
58	1904, 28	Humble (Deep and Shallow)	Harris	Cap; Mio. Yegua; Eoc	17.0-45.0	2,200	60
59	1937	Joes Lake	Tyler	Wilcox Sd; Eoc	40.0-47.0	2,000	30
60	1938	League City	Galveston	Frio; Olig	40.0	740	20
61	1930, 42	Livingston (all pools)	Polk	Cockfield, Cook Mt, Wilcox; Eoc	40.0	1,800	20
62	1936	Lochridge	Brazoria	Frio; Olig	26.0	1,900	15
63	1933	Louise	Wharton	Frio; Olig	26.0-38.0	1,600	15
64	1938	Lovells Lake	Jefferson	Frio; Olig	26.0	3,200	20
65	1936	Magnet-Withers (incl N. Withers)	Wharton	Frio; Olig	26.0	14,920	20
66	1931	Manvel	Brazoria	Frio, Marg; Olig, Mio	26.0	1,800	15
67	1908	Markham	Matagorda	Cap; Mio	25.0-40.0	500	20
68	1938, 41	Markham, North	Matagorda	Carlson, League, Cornelius, Frio, Markham, Braman	36.0	1,350	20
69	1942	Mercy	San Jacinto	Wilcox; Eoc	38.0	1,680	20
70	1936	Nome	Jefferson	Marginulina; Olig	27.0	800	20
71	1934	Old Ocean	Brazoria	Frio; Olig	52.0-68.0	10,700	200
72	1913, 37	Orange (incl West)	Orange	Frio; Olig, Mio	20.0-42.0	650	30; 8
73	1941	Oyster Bayou	Chambers	Frio; Olig	36.0	1,400	20
74	1935	Pickett Ridge	Wharton	Frio; Olig	26.0	1,200	15
75	1921	Pierce Junction	Harris	Frio, Vicksburg; Olig, Mio	21.0-41.0	350	45
76	1929	Port Neches	Orange	Frio; Olig, Mio	25.0	300	40
77	1939	Port Neches, West	Orange	Frio; Olig, Mio	38.0	400	40
78	1927, 34	Raccoon Bend	Waller, Austin	McElroy, Cockfield; Eoc	26; 33	1,000	35
79	1940	Red Fish Reef	Chambers	Frio; Olig	35.0-57.0	1,800	15
80	1901	Saratoga	Hardin	Cap; Mio, Olig	17.0-21.0	1,000	50
81	1936	Seabreeze	Chambers	Frio; Olig	40.0	700	30
82	1936, 38	Segno (Deep and Shallow)	Polk	Wilcox, Cockfield; Eoc	36.0-44.0	2,200	20
83	1936	Silsbee	Hardin	Cockfield; Eoc	36.0-43.0	1,100	20
84	1944	Smith Point	Chambers	Frio; Olig	42.0	640	25
85	1902	Sour Lake	Hardin	Mio, Olig, Eoc	16.0-31.0	1,000	100
86	1935	South Houston	Harris	Frio; Olig	20.0-25.0	640	75
87	1925	South Liberty	Liberty	Yegua; Eoc, Mio, Olig	21.0-47.0	350	60
88	1901	Spindletop	Jefferson	Cap; Mio. Frio; Olig	25.0	900	50
89	1941	Stowell	Jefferson	Marg, Frio; Olig	35.0	3,200	100
90	1928	Sugarland	Ft. Bend	Marg, Frio; Olig, Mio	28.0-35.0	1,200	60
91	1931, 39	Thompson (incl N&S)	Ft. Bend	Frio, Vicksburg; Olig, Mio	25.0-43.0	6,500	25
92	1933	Tomball	Harris	Cockfield; Eoc	37.0-41.0	8,900	20
93	1935, 34	Turtle Bay	Chambers	Various	32.0	1,000	20
94	1937	Webster	Harris	Frio; Olig	30.0	4,000	100
95	1936	West Beaumont	Jefferson	Mio, Olig	26.0-34.0	650	15
96	1902, 37	West Columbia (Old and New)	Brazoria	Frio; Olig, Mio	28.0-30.0	2,030	110
		R. R. Com. Dist. 4					
97	1928	Agua Dulce	Nueces, Jim Wells	Frio; Olig	40.0-60.0	5,300	30
98	1938	Alice	Jim Wells	Frio, Vicks; Olig	46.0	1,280	14
99	1936	Aransas Pass	San Patricio	Frio; Olig	43.0	6,200	9

From The Petroleum Data Book, Second Edition, which carries 750 pages of information on the petroleum industry.

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PROPERTIES OF CRUDE OILS PRODUCED IN UNITED STATES

(Continued) **(Analyses of Selected Representative Crudes)**

No.	State Field (formation, zone, age)	Gravity, °API	Sulfur, per cent	S. U. Viscosity at 100° F, seconds	Carbon residue of residuum, per cent	Gasoline and naphtha	
						Per cent	°API gravity
	Kansas						
1	Bornholdt (Miss. limestone, chat)	34.8	0.62	59	18.0	29.2	63.9
2	Burrton (Miss. limestone, chat)	32.5	0.56	60	11.2	23.4	57.2
3	Fairport (Oswald, Lansing lime., Penn.)	41.5	0.33	41	13.8	38.0	65.0
4	Geneseo (Arbuckle limestone, Cam.-Ord.)	39.4	0.53	40	15.4	34.0	65.6
5	Goodrich (K. C. limestone, Penn.)	35.6	0.31	45	8.4	27.3	58.9
6	Gorham (Topeka lime., Shawnee; Penn.)	36.6	0.50	47	13.3	31.7	64.8
7	Graber (Hunton limestone, Sil.-Dev.)	40.4	0.16	38	9.5	36.2	61.8
8	Hall-Gurney (K. C. limestone, Penn.)	38.8	0.41	42	13.4	34.3	62.6
9	Hollow-Nikkel (Miss. limestone, chat.)	34.0	0.40	51	8.2	26.6	57.7
10	Oxford (Arbuckle lime., Cam.-Ord.)	38.0	0.22	39	10.6	30.7	59.5
11	Rainbow Bend (Burbank sand, Penn.)	42.3	0.13	37	6.9	36.5	62.1
12	Ray (Reagan sand, Cam.)	32.3	0.58	70	16.7	25.6	60.8
13	Raymond (Arbuckle lime., Cam.-Ord.)	43.0	0.31	36	10.0	44.7	64.5
14	Richardson (Arbuckle lime., Cam.-Ord.)	41.5	0.31	38	11.3	35.6	61.3
15	Ritz-Canton (Miss. limestone, chat)	37.4	0.50	48	13.1	32.8	64.5
16	Russell (Lansing-K. C. lime., Penn.)	38.2	0.38	44	12.1	33.4	61.5
17	Valley Center (K. C. lime., Penn.)	33.8	0.49	55	7.8	26.0	59.2
18	Wherry (Miss. limestone, chat)	38.4	0.61	48	7.7	30.7	66.1
	Louisiana						
1	Anse La Butte (Plio. and Mio. sands)	37.8	0.10—	38	3.1	28.5	56.4
2	Black Bayou (Mio. sands)	24.9	0.18	54	3.5	8.3	53.2
3	Bosco (Discorbis sand)	37.6	0.10—	40	2.1	17.8	54.2
4	Caddo District (Annona chalk, Cre U.)	36.0	0.22	45	6.8	23.8	52.7
5	Cameron Meadows (Mio U. sand)	31.5	0.10—	41	3.9	9.2	49.7
6	Charenton (Mio. sand)	36.0	0.10—	44	1.7	15.7	54.4
7	Cheneyville (Cockfield)	46.3	0.10	33	6.0	52.8	61.3
8	Darrow (Mio. sand)	35.0	0.19	44	5.4	22.5	58.4
9	Erath (Mio U. sands)	52.0	0.10—	32—	2.4	55.4	60.5
10	Garden Island (Mio. sand)	37.8	0.15	40	6.2	31.1	53.7
11	Gibson & Gibson N.E., (Mio U. sands)	37.4	0.10—	43	1.1	12.1	52.5
12	Grand Lake (Mio U. sands)	32.8	0.10—	47	3.1	6.7	49.7
13	Hackberry, East (L. Marginulina sand, Mio L.)	35.0	0.26	39	6.3	29.9	56.4
14	Holly Ridge (Massive sand, Tusc. form., Cre U.)	37.4	0.17	44	7.7	25.8	60.2
15	Homer (Nacatoch sand)	37.8	0.66	45	10.8	31.0	63.1
16	Jeanerette (Mio U. sands)	35.6	0.10—	44	3.3	13.1	51.3
17	Lake Long (Mio U. sands)	42.6	0.10—	35	1.9	31.0	55.7
18	Lake Salvador (Mio U. sands)	35.8	0.13	46	4.4	14.8	53.7
19	Lisbon (Pettit limestone)	32.1	1.10	68	15.9	22.2	60.5
20	Pine Prairie (Yegua sand, Cockfield form., Eoc.)	40.9	0.14	38	5.5	32.7	59.5
21	Port Barre (Mio L., Olig., Eoc. sands)	32.8	0.29	46	8.0	22.8	52.7
22	Potash (Mio U. sands)	29.5	0.37	62	12.6	23.9	57.7
23	Quarantine (Mio U. sands)	35.8	0.12	44	5.3	18.6	53.5
24	Roanoke (No. 5 sand, Heterostegina, Mio L.)	38.2	0.10—	40	6.2	29.8	55.9
25	Sligo (3100 ft. lime.)	41.1	0.27	40	9.3	33.9	62.9
26	Sugar Creek (Darrett zone, Carter lense)	34.2	0.94	54	16.0	21.6	51.6
27	Tepetate (Ortego sand)	41.7	0.13	35	4.9	42.4	62.3
28	Ville Platte (Sparta sand)	40.4	0.11	40	6.8	28.8	59.7
29	White Lake, East (Mio U. sands)	36.2	0.10—	40	1.5	14.0	53.7
30	Woodlawn (Marginulina sand, Mio L.)	38.8	0.10—	37	3.3	25.1	54.4
31	Woodlawn, condensate (Hackberry sand, Mio L.)	52.7	0.10—	32—	0.8	72.6	57.4
32	Zwolle (Chalk rock)	41.9	0.16	37	5.4	30.5	56.2
	Montana						
1	Pondera (Madison lime.)	31.9	1.59	52	15.3	30.9	60.7
	New Mexico						
1	Cooper (Big limestone, Permian)	28.4	1.57	62	11.4	20.4	55.4
2	Langlie (Permian sand)	34.8	1.35	39	11.5	36.5	53.7
3	Loco Hills (Loco sand)	36.6	1.02	41	8.7	36.2	56.2
4	Mattix (Permian sandstone)	40.0	1.26	35	10.9	43.0	60.8
5	Penrose (Permian sandstone)	38.6	0.93	37	8.0	38.5	58.9
	New York						
1	Richburg (Richburg sand)	44.1	0.10—	42	2.0	32.9	62.3
	Oklahoma						
1	Apache (Wilcox sand, Ord.)	38.8	0.38	41	7.2	31.3	59.2
2	Bird Creek (Burgess sand, Penn.)	37.6	0.16	42	5.3	28.9	59.7
3	Cromwell (Cromwell sand, Penn.)	39.8	0.13	39	5.1	35.4	60.8
4	Earlsboro, North (Wilcox sand, Ord.)	30.4	0.69	67	15.2	23.3	62.9

Note: The foregoing analyses are supplementary to those appearing in the 1947 edition of *The Petroleum Data Book*.
Source: U. S. Bureau of Mines.

From The Petroleum Data Book, Second Edition, which carries 750 pages of information on the petroleum industry.

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Oil Around the World*

T. S. PETERSON†

It gives me a great deal of pleasure to be able to speak before this group, even though my own experience in the oil business has not been in the field of petroleum production. I would not attempt to bring you a technical discussion but I would like to sum up the worldwide status of oil generally, and the prospects for California in particular.

Even though many of you are familiar with the facts covered in this discussion, I feel that such a summing up is vitally important for all of us in the oil business. We have come so far in the last few years that we cannot act intelligently today, or plan ahead for tomorrow, without pausing periodically to look around. We have got to evaluate where we are, remember how we got here, and determine so far as possible just what there is that lies ahead.

The average American of yesterday rarely looked beyond the end of Main Street. His concern was the community in which he lived and his interest in the rest of the world was governed by the extent of his curiosity. Today, most thinking Americans realize that they are citizens of the world and that events in far-off places can involve them whether they like it or not.

The same is true of the oil business. Whether it wanted to or not the American oil industry has become international in scope and effect. And we have all got to realize that a new discovery in some odd corner of the globe is no longer just an object of curiosity. It is an event that has its economic effect on the whole of the industry everywhere.

With this thought in mind it becomes apparent that the oil men in California, or any other state, cannot afford to ignore what oil is doing in every other part of the world.

Let us therefore take a look at where we stand today. The general thinking of the people at large subscribe to the title of a recent editorial, which appeared in the Wall Street Journal. Simple, and short, it sums up the general situation with these words: "Too Much Oil."

Actually, and I think that you will agree with me, this is an oversimplification and not necessarily true. Having too much oil is a little bit like having too much money. Unless someone is going to take it away from you, how can you ever say that you have too much money? Or what kind of limitation would you want on your own bank account?

Because oil is a trade commodity of international flavor, like wheat and corn and coffee, the casual observer tends to regard its accumulation in much the same way. But we know that it bears little actual resemblance to these other international commodities. First, because when agricultural products of the soil have piled up to the point where all available storage is filled, there is nothing left for the rest of it but to burn it, or leave it to rot in the fields. In overproduction, an agricultural commodity loses much of its value, though only temporarily. It has only a temporary status anyway for when the available supply has been used up another good year in the wheat fields or the corn belt or in the coffee plantations, can grow enough to replace that which was consumed.

Oil, on the other hand, is a world commodity that does not have to be taken from the land just because the harvest season is at hand. It can be left in nature's own storehouse because it has been ripe for many millions of years already, and a few more years won't hurt it any. But the big difference, it seems to me, lies in the fact that petroleum is NOT replaceable. We can't count on a good growing year or a few favorable seasons to replace that which we have taken from the earth.

Therefore it seems a little foolish to say that there is "too much oil." Over the long haul and at the ever-increasing rate of world consumption there actually isn't enough oil to keep us going forever.

If there's too much of anything in the oil industry, it's the ability to produce. Worldwide, oil production potential has been built up in the last 10 years to meet the demands of abnormal conditions. Among these I include the unprecedented needs of the

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civilian and military machines of war, and the great postwar surge of construction and reconstruction. Now we have settled back to an era of normal growth and the industry worldwide is passing through a period of readjustment.

The oil needs of every part of the world are being met and the industry is generally trimming its producing sails to satisfy these needs without waste. Because there is enough oil coming out of the ground to fulfill the worldwide demand a competitive marketing situation has developed that involves not only individual companies but even nations and blocs of nations that are geographically grouped together.

This, then, is the world oil situation today as expressed in a general way. Now, let's take a closer look at the individual parts which make up this jigsaw picture of oil around the globe. And let's use a few figures to further clarify a picture which is somewhat fuzzy when viewed overall.

Consumption Gains

Ten years ago the world produced and consumed some 5,000,000 bbl of oil each day. The United States and South America brought enough crude out of the ground to supply the needs of the Western Hemisphere, and in addition supplied most of the oil consumed in Western Europe.

Today, world consumption has risen to more than 9,000,000 bbl daily. Production in the United States and South America still is enough to amply supply Western Hemisphere demand but much of its market in the Eastern Hemisphere is gone. Compared with 60 per cent in 1938, the Western Hemisphere last year supplied Western Europe with only 35 per cent of its needs.

Europe's rate of consumption has risen from 750,000 bbl daily pre-war, to more than 1,000,000 bbl a day at present. While South America has continued to ship about 300,000 bbl per day to this foreign market, the movement from the United States has been reduced during this time from 250,000 bbl to about 70,000 bbl a day. This slack of more than 500,000 bbl daily in the European market has been taken up by the production growth in that part of the world which the statesmen term the Middle East.

The Eastern Hemisphere still is not producing and refining enough oil to satisfy its own needs, but it has come a long way in the last few years. With more than half of the world's proved reserves it should continue to depend less and less in the future upon the production of oil on this and the South American continent.

As to the immediate future, we can expect that the next few years will see some further reduction in the Western Hemisphere's exports to Europe and Asia as Middle East production and transportation facilities are augmented and new refining capacity is built in Europe. The United States has long exported more oil than it brought into this country, and it will continue to be an important source of some refined products. But with the growth of production and facilities outside the U. S. we must expect that this country cannot continue its traditional exporting role in the face of foreign competition.

The United States has by far the largest consumption of petroleum products in the world—some 60 per cent of the world total. To meet this demand of more than 6,000,000 bbl daily, we are depleting our reserves at a more rapid rate than the Eas'ern portion of the globe. True, we have been fairly successful in finding new oil reserves — successful enough to have increased our known reserves each year until in the United States they now stand at the highest figure in history. But the prospects abroad have not been explored to anywhere near the extent they have on this side of the Atlantic.

As the Middle East has become a more prominent producing area of the world in the last few years, you may be interested in a brief review of operations in that part of the world.

The major companies operate in an area that hangs like a horseshoe over the northern portion of the Persian Gulf. They are Anglo-Iranin, Arabian American, Iraq Petroleum, Kuwait Oil, and the Bahrein Petroleum Company. In addition, the Neutral Zone lying between Kuwait and Saudi Arabia has recently attracted two smaller American concerns, Pacific Western and American Independent.

Anglo-Iranian holds the concession rights to Southwestern Iran where it first discovered oil in 1908. Currently this company is producing about 600,000 bbl daily, practically all of which is processed at the company's Abadan refinery, one of the world's largest. The strength of Midle East fields, such as those held by Anglo-Iranian, is indicated when you realize that this production of more than a half-million barrels comes from 8 fields in which there are some 80 producing wells. Compared with an average rate of 100 bbl per well in South America and only 12 bbl a day for United States wells, the average production rate in this part of Iran is 7500 bbl per well each day!

A majority interest (53 per cent) in this company is held by the British government and another 25 per cent of the voting power is in the hands of the Burmah Oil Company, Ltd. Thus Anglo-Iranian is seen to be one of the aces in the hand which Great Britain holds in the present world oil poker game. The pot, of course, is the world oil market outside the U. S. But that situation is something I'll leave for right now until we've covered the other companies operating on the other side of the world.

Second in importance in the Middle East—and its production is not very far behind — is the Arabian American Oil Company. This company, Aramco, is wholly owned by four American corporations, and represents America's major holding in the prolific Persian Gulf area.

Aramco's growth is marked from the date of first commercial production in 1938 but the war interfered with development of the Saudi Arabian fields to a great extent. In fact, Aramco's real growth has come only in the last 5 years for by 1945 its production had been built up only to about 58,000 bbl daily. Since then it has been increased in 1946 to 164,000 bbl; 1947, 246,000 bbl; 1948, 390,000 bbl, and in 1949 Saudi Arabian production averaged 477,000 bbl.

This is the company pioneered by the Standard Oil Company of California, which now is owned by Standard of California, The Texas Company, Standard of New Jersey, and Socony-Vacuum. In the 12 years since it brought in its first commercial well, Aramco has built a refinery at Ras Tanura, and also has fostered a sister organization, Trans-Arabian Pipe Line Company, which now is building a 1067-mile pipe line from the Saudi Arabian oil fields to the Mediterranean. When completed it will be capable of transporting some 300,000 bbl daily.

Another company of international flavor is the Iraq Petroleum Company, Limited, which holds a number of concessions in Iraq, Syria, Hashemite Kingdom of Jordan, Israel, and along the Trucial Oman coast on the Persian Gulf. Although Iraq Petroleum has developed 5 fields, its current production is limited to 2—the Kirkuk Field in Iraq, which now is producing some 140,000 bbl a day and the Dukhan field in Qatar, producing 40,000 bbl daily. As an aside from its oil-producing capacities, this company has a very interesting background. Its antecedants go back to the Turkish Petroleum Company, formed prior to the First World War by the Germans, English, French, and Dutch. To this was added an American flavor when our State Department after the war secured U. S. par-

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ticipation of 5 American companies. These were Jersey, Socony, Gulf, Atlantic, and Pan American Petroleum Company. Since then these last named three American companies have dropped out, and Iraq Petroleum now is owned by Royal Dutch Shell, Compagnie Francaise de Petroles, Anglo-Iranian, Jersey and Socony, and an Armenian gentleman by the name of C. S. Gulbenkian, who controls 5 per cent of the Iraq group.

A comparative newcomer in the Persian Gulf, so far as production is concerned, holds one of the largest, if not the largest, single oil field in the world. This is the Kuwait Oil Company, Ltd., whose reserves in the Burghan field have been estimated at about 11 billion barrels. Although Kuwait's oil operations were practically discontinued during the recent war, drilling has been greatly accelerated there during the last 4 years and production now is running about 275,000 bbl a day. Kuwait is another example of international ownership, being equally owned by Anglo-Iranian and Gulf. Anglo-Iranian is reported to be lifting its share of the crude and a substantial part of the remainder is sold to Shell under a long-term contract.

These 4 companies, then, are the principal producers of the Eastern Hemisphere. There is production of some 30,000 bbl daily on Bahrein Island and roughly 200,000 bbl a day total in the East Indies. But for the most part the major companies in the Persian Gulf area control the supply of Eastern Hemisphere crude that finds its way to the European markets and those in the area East of Suez.

Supply Plentiful

All of these companies lived more or less happily together during recent years because they were striving for production which would meet the Eastern Hemisphere demand for oil. But in the last year the petroleum industry in this part of the world entered a new phase. Supplies of crude, which had been inadequate in the immediate post-war years, became plentiful. For the first time in many years there were more than enough sea-going tankers and several companies were building or planning major pipe lines to Mediterranean terminals. But while the physical problems of supply were being solved — there remained only a lack of sufficient refining capacity in Western Europe—the problem of currency exchange became a real headache for those American companies operating outside the U. S.

I think that most of you are at least aware of the general situation which has come to be known in the nation's press as the "sterling-dollar oil controversy." In summation, most foreign countries are short of dollars and now that British-controlled production in the Middle East is approaching the demand level of a large part of the Eastern Hemisphere, dollar oil is being forced out of these foreign markets.

It also is being forced out of many markets by the recent British edict banning sale of dollar oil in those countries whose currency is tied to the British pound sterling. And this is the [illegible] of the whole so-called "controversy." The American companies —those whose foreign production has been labeled "dollar oil" — have a justifiable complaint about this discrimination. Indeed, some opinion discounts a large part of the British contention that the move was made because of dollar shortage entirely. One might suspect that it has commercial as well as so-called dollar shortage implications and I have heard opinions from those who believe that the British government is using sterling control to gain itself a sizable portion of world oil markets.

This situation is one that has led naturally to a great deal of talk regarding oil imports. Segments of our American industry have become concerned over the possibility that this displaced oil might be diverted to the United States.

And as most of you know, imports have been vigorously opposed by some of the domestic oil producers of the United States, who maintain that such imports threaten the very existence of the domestic oil industry.

Right here, and now, I would like to state that the Standard Oil Company of California is a domestic oil company, too, and that we have a whole lot more interest and investment in our operations in the United States than we have in foreign countries. Of our company's total investments only 6½ per cent are represented by investments outside the United States. Certainly, we would not advocate any import program that we felt would be, in the long run, injurious to the petroleum industry of America. We believe that some imports are a good thing for the welfare of this country as a whole, but the domestic industry must still be maintained in a healthy and vigorous state, as is advocated by the National Petroleum Council. Imports today may be affecting domestic production yet they also are providing a vitally needed cushion against a possible war. This cushion is the approximately 1,000,000 bbl of potential daily production, which is being held in underground storage. I believe that the development of the domestic industry is not being drastically retarded by the imports, which are reducing the unratable depletion of America's long-range resources. The continuing active exploration program in the United States, which added one and one-half billion barrels to our reserves during 1949, is witness to this. And, as the Wall Street Journal stated editorially in a recent issue:

"If there is any reason to conserve our own supply, imports work to that end."

California Situation

Let's now take a look at the overall picture of oil in California. During the time a few years ago when we were pushing all production in this state to meet an unprecedented post-war demand, there were many who saw the import of oil into California as a condition that was just around the corner. Certainly that picture has changed in the last year. The prospect of bringing large shipments of crude up the coast from South America for processing here is still a possibility for the future. But it has moved a long way into the future. I can't see it as a practical probability during the next 10 years at least. And beyond that, I don't think anyone can guess or predict in this changing world of ours.

At the present time production of crude oil in California has dropped back to about 860,000 bbl per day as compared with the all-time high of 953,000 bbl a day reached in November 1948. Discounting Elk Hills at a maximum efficient producing rate there is about 130,000 bbl a day shut in because we here in California are able to produce more crude oil—particularly heavy crude—than we can use or sell elsewhere.

This is a situation that has been the result of a number of things and one that is not liable to change much within the next few years. As to the factors responsible, there are several and I would like briefly to discuss each of them here.

Number one is the growing dieselization of Western railroads. The railroad industry began the switchover to diesel power only a relatively few years ago but already about half of the industry work in the West requires this type of petroleum fuel. Within another 5 years we can expect this number to reach 75 per cent, and eventually 90 to 95 per cent of train movement in this area will be powered by diesels.

The railroads have been making this switch for a very good reason—it costs them less to operate this type of engine. And of course it has developed a fine market for the sale of

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diesel fuel by the petroleum companies on the Pacific Coast. It has, however, also meant the loss of a big market for heavy fuel oil. If these engines burned diesel fuel gallon for gallon with the amount of heavy fuel oil needed to do the same job then the problem would be only that of one product displacing another. But the modern diesels are so very efficient that they can make a gallon of diesel fuel do the work of more than four gallons of heavy fuel oil. And that's where the rub comes in, and where the fuel oil starts to pile up in the storage tanks.

Fuel oil is also in oversupply for another reason. This is the import of large quantities of natural gas into California. At the present time some 330 million cubic feet of this fuel are being brought in from Texas and New Mexico every day. Some of it is going to householders and this amount isn't materially displacing any oil products. But in order to supply these householders during the peak load months of winter, the gas transmission companies must build big pipe lines. Then, when domestic consumer loads decrease in the spring and summer months there is more gas available than can be sold to these regular customers. The result is that this natural gas is sold to the big industrial and utility consumers who burn fuel oil part of the year and gas during that part of the year when they can get it at a reduced price. This quantity of natural gas, sold to industrial consumers has also displaced heavy fuel oil during a part of the year at least.

Add to this situation the huge pipe line now being constructed to bring additional natural gas in northern California from Texas and New Mexico and you can see an even further dropping away of the industrial fuel oil market. For those of you not familiar with this project, the California portion of this big line is being built by the Pacific Gas and Electric Company and will reach from the Arizona border to San Francisco Bay. It is expected to be in operation by November of this year and the initial throughput will approximate 150 million cubic feet daily. This figure is expected to double within a year, and the ultimate capacity of this line probably will be 500 million cubic feet a day.

As a rule of thumb measure, 6000 cu ft of gas has the same heat value as a barrel of oil, so that this line alone is roughly the equivalent of 80,000 bbl of oil daily.

And as long as we're talking about natural gas displacing fuel oil as a source of domestic and industrial heat, we may as well look into the future in the Northwest. That part of the Pacific Coast always has been the stronghold of burner oil sales. Now oil in this area is faced with competition from the tremendous gas fields of Southwestern Canada. Several companies are competing for the favor of the Canadian government, each seeking permission to build a pipe line to the Puget Sound area. This line could conceivably be completed within the next two years and would bring with it an estimated import of natural gas at the rate of 200 million cubic feet a day.

Two other factors that must be considered are the partial loss of the Pacific export markets and the decrease in shipping from Pacific Coast ports. With appreciably less ship movement from the harbors of this coastline has come a corresponding drop in sales of heavy fuel oil to the ships which formerly bunkered here. This is a maritime problem which has been with us since the end of the war and for which there appears to be no early solution. The loss of some export sales to the Far East, which includes shipments of crude oil, can be attributed to the increased competition from Middle East oil and the growing production in the East Indies.

All of these things are on the minus side of the oil production and sales picture for the Pacific Coast. On the plus side, we have two factors that have contributed to increased demand in this area during the last 10 years. Of first importance is the economic growth of this area as indicated by a swelling population. Second is the factor that not only are more people using oil products but with an advancing standard of living the same people are using more oil. A recent survey indicates that 6.2 per cent of all American car-owning families now possess two or more automobiles. In 1948 only 4.8 per cent owned more than one car. Another indicative estimate places the automobile population of the U. S. at 42 million by 1955 and 45 million by 1958.

We cannot look forward to the tremendous rush of people to the coast which was brought on by the war and the immediate post-war years of population readjustment. But we can look forward to a continued steady growth. Part of this will be the result of immigration of people from the East and Middle West. And part of it will be the result of a current trend to higher birth rates. It will be a long time, however, before the oil product demand growth tied to population increase catches up with this state's ability to produce crude oil. And it will be an even longer time if our discoveries of new fields such as Cuyama Valley continue at anywhere near the same rate they have followed in the past. As you well know, all the oil in California hasn't been found yet and I can see no lessening of the general rise of petroleum reserves as reported by the API in the last few years.

With all of this in mind and looking into the foreseeable future, you can see that the problem in the West is not whether we have sufficient crude oil supply. Rather, our big problem is in the field of converting more of this crude into the type of products for which there is a substantial market and a good price.

A number of oil companies on the Pacific Coast already have made plans in this direction and some have actually begun conversion of refining facilities to turn out a larger percentage of high-use products such as gasoline and diesel fuel. This trend undoubtedly will continue because California refiners cannot continue to turn out heavy fuel oil for which there is a diminishing market and they must meet the needs of a growing consumer market for such products as gasoline.

Thus, in summation, I would observe that in California we have entered an era of stabilization in which the petroleum industry must adjust itself to shifting demands for products. It is an era in which the present potential oil production of the state plus future discoveries is ample to care for the foreseeable needs of the Pacific Coast area that California supplies.

Worldwide, the potential also is enough to meet present demands and take care of normal growth and the problem here is the fight of foreign oil—both dollar and sterling—for the available foreign sales.

There are difficulties, both here and throughout the world, which I have outlined for you. But none of them are insurmountable difficulties, to be regarded as threatening the future of either oil men or oil companies. Rather, they are the manifestations of problems which result from the normal workings of the economic law of supply and demand and which can be met by the adjustment of the industry to this inevitable law.

As I mentioned in the beginning, we in California can no longer afford to confine our understanding to oil production in this state. We have come to realize that we are a part of an international industry dealing with an international commodity and it will require the efforts of all of us to bring about this industry's adjustment so that it reflects most favorably on the interests of the United States, which is our primary interest after all. * * *

Pathfinding in Fuels and Engines*

T. A. BOYD†

THIRTY years ago gasoline to most automotive engineers was simply a liquid that came in a red can. At that time Harry L. Horning was one of the few men who had the insight to recognize the importance of fuels in relation to the design and the behavior of engines. He played a major part in initiating research on the subject, and during his lifetime in helping to conduct it — notably the cooperative research that in the years since has been such a big factor in advancing the understanding of fuels and the more nearly perfect fitting of fuels and engines. It was to aid in forwarding that cause still further that the Horning Memorial Award was established by Mrs. Horning.

The Horning Memorial lecture by C. B. Veal, presented at the annual meeting four years ago, was devoted to the history and philosophy of cooperative research (1). In that lecture Veal said this: "A topic becomes ripe for cooperative research (only) when a certain level of common knowledge concerning it has been reached." It has therefore appeared to me that this lecture might with profit be devoted to the pioneering stages of research that must precede the cooperative phase.

As it happens, I have had for many years a ringside seat at a pathfinding program of fuel and engine researches. This research, began in 1916 by Charles F. Kettering and continued under his direction until his retirement in 1947, is still in progress. It has been thought that an account of that program — of its gropings, its failures, and its successes—might be of interest. Also, it might possibly assist to some slight degree in furthering "the art of mutual fuel and engine adaptation," particularly in helping to suggest how far from finished research in the field still is today. Many persons have contributed to the researches to be reported, although at no time was the group a large one.

It was in a very humble way that the long research began. The place was an old building that had been a tobacco warehouse. The first effort was to find out something about knock. Just a few years earlier knock had begun to appear in automobile engines. It came when the production of gasoline was boosted to meet an increasing demand, thus lowering its volatility and reducing its freedom from knock. The prevalence of knock then had been used by some in an effort to discredit battery ignition, a fundamental part of electric self-starting, which was new at the time. Spark knock it was called. Knock had also forced a low compression ratio on the engine of a home lighting set developed to run on kerosine. Ever since the beginning of this program of research the effort has related chiefly to the bugbear of knock, which is the greatest shortcoming of gasoline as an engine fuel.

The very first thing done was to put an optical indicator on a one-cylinder, aircooled engine. That instrument was one made in England and previously secured for such possible use. The effort was to see what could be learned about knock, which at the time was commonly supposed to be caused by preignition. A beaverboard enclosure was built around the little engine. In that way a sufficient degree of darkness was attained to use an optical indicator.

The first picture of pressure events in the engine cylinder was obtained by a very improvised method. The indicator was supplemented by two pieces of lath, two shingle nails, and a tomato can. Out of those parts a film drum was made that could be rotated —by hand—in the path of the beam of light from the indicator. A piece of photographic paper was put around the tomato-can drum and secured there by rubber bands. Then, with the engine running under knocking conditions, Kettering spun the tomato can on its shingle-nail pivots and Mr. Midgley (Thomas Midgley, Jr.) opened the shutter of the indicator.

It was by that make-shift means that the first photographic cards of knocking events in an engine were obtained. And those pictures yielded this important item of information: Knock does not come from preignition at all. It is a violent pressure disturbance that comes after ignition by the spark plug.

Speculating then on why kerosine knocks worse than gasoline, it was reasoned that the difference might be due to volatility. It was recalled that the wild flower, the trailing arbutus, with its red-backed leaves, blooms early in the spring, even under snow. And it was thought that if only kerosine were dyed red it might absorb enough more heat to make it vaporize better, and so behave like gasoline. But no red dye happened to be available there then—it was Saturday afternoon. So a bottle of iodine was pulled down from the shelf with the suggestion that iodine ought to dye kerosine red. And when kerosine made red with that iodine was run in the engine, sure enough, the knock was greatly reduced! So the fine theory was apparently confirmed.

But when soon afterwards kerosine made red with a regular dye was run there was no effect whatever on the knock, no matter how deep the dye. Nevertheless, out of that theory had come the important discovery that knock is suppressed by the presence of a minute amount of iodine. It was not that iodine was important of itself, for it could not be used in a practical way, but that it showed that powerful chemical antiknock agents do exist. So as an incentive to effective action that theory, incorrect though it proved to be, turned out to be one of the important stepping stones in the path of progress.

Interlude of First World War

Soon after that time came the entry of the United States into the First World War. Then the search for a more nearly knock-free gasoline for use in fighter planes was undertaken, partly in collaboration with the Bureau of Mines (2). In investigating the knocking properties of the various types of fuel compounds then available, it was found that the chemical structure of a fuel is the most important factor in respect to knocking tendency (3). One of the observations that opened the eyes of the investigators to this important item of knowledge was that ethyl ether, the kind used for anaesthesia and which at that

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time was sometimes employed also as an aid in starting, is a particularly bad knocking compound. On the other hand, butyl alcohol did not knock in any of the engines they had then (3). But those two compounds have precisely the same ultimate chemical composition, $C_4H_{10}O$. They differ only in structure or molecular architecture.

It was also during that wartime work, pursued for the army and in cooperation with the Bureau of Mines, that the first synthetic high-octane aviation fuel was made. That fuel was composed of 70 parts cyclohexane and 30 parts benzene. The cyclohexane was made by hydrogenating benzene in the presence of a nickel catalyst. The effort to hydrogenate benzene was undertaken against advice that it was impracticable. Leo H. Baekeland, famous chemist, inventor of Velox and Bakelite, and member of the Naval Consulting Board, told Kettering that he would give him a wooden medal if he and his men could make a pint of cyclohexane. Nevertheless, after an intensive research and some failures, it was found that the job could be done successfully. By present standards—standards not yet in existence then—that first synthetic aviation fuel had an octane number of 75 at lean or cruise fuel-air ratio and of about 100 at rich or take-off mixture. Those values are to be compared with a rating of only 50 to 55 octane number for the aviation gasoline of that time, whether at lean mixture ratio or rich.

As for Dr. Baekeland and his prediction of failure, a bottle of cyclohexane was ceremoniously presented to him, together with a proposed design for the wooden medal he had promised. The latter was in the form of a humorous diagram, a benzene ring surrounded by cats, to suggest catalysis. The outcome was so pleasing to Dr. Baekeland that that bottle became one of his prized possessions, and he kept it on his desk for a long time afterwards. The reason Dr. Baekeland prized that bottle of cyclohexane, when his prediction regarding it had turned out to be so far wrong, was that his own experience in research had taught him, as he expressed it, "to bow humbly before the facts, even if they do not seem to agree with my favorite theories."

Quest for Antiknock Agent

After the war ended in 1918 the effort to find a practical cure for the noisy bugbear of knock, which barred the way to higher engine powers and better fuel economies, was taken up again. In doing so, we had the feeling that nature would not have given to one element the knock suppressing property iodine had without giving the same property in some degree to another. Not having any better basis on which to proceed, it was planned to try in a systematic manner at least one compound of each of the elements. That did not prove to be easily possible, however. Testing compounds not soluble in gasoline did not in general turn out to be practicable. Compounds of only a few of the elements soluble in gasoline were available, and synthesis of suitable compounds of other elements was difficult and extremely tedious.

As luck would have it, though, the search for a practical antiknock agent had been pursued only a short time when it was discovered that the nitrogen compound aniline and the other aromatic amines similar to it are effective knock suppressors. It was very fortunate that that discovery was made thus so soon. For we were surely not certain enough at that stage that there would be any such thing as a practical antiknock agent to carry us through a long search.

The aniline-type compounds seemed so nearly practical that, although the search for still other antiknock agents was continued as opportunity offered, the most of the activity of the group for many months was put into the effort to develop to a commercial stage the use of the aniline compounds as knock suppressors. The incentive for this was the desire to conserve gasoline by improving fuel economy through making it possible to boost the compression of automobile engines. For at that time there was grave apprehension about the early failure of crude oil reserves. The best authority of that time, the U. S. Geological Survey, was predicting that petroleum would be exhausted within a very few years, and that after a period as short as three years production might begin to fall off (4). So serious did the situation appear that some of the activity of our small group at that time was even devoted to the possibility of converting vegetation into alcohol as a supplementary source of motor fuel (5).

On the aniline-type compounds we measured the relative antiknock effects of all of the different ones that could be obtained, and several were made especially for the purpose (6). We struggled with the problems of low solubility of aniline in gasoline and the unpleasant stuffy odor of the compounds, particularly in the engine exhaust. In the effort to minimize the cost, which was a cause of concern because the concentration needed to prevent knock was 3 or 4 per cent of the gasoline, a great deal of work was done to develop injectors for introducing the compounds only when required.

The compression ratio of the engine in an experimental car was boosted from the then normal value of 4 to 1 up to 7 to 1. That car was driven on gasoline containing toluidine, one of the aniline-type compounds that had solubility in gasoline good enough to permit it. The car had such high performance or such unusual hill-climbing ability for that time—and also its engine and the exhaust from it smelled so badly from the toluidine used—that it was dubbed "The Goat." But it gave an increase of 40 per cent and more in miles per gallon over the car of conventional compression ratio, thus demonstrating the benefits of a fuel that would make possible the use of higher compression ratios.

The army men at McCook Field were interested in the new antiknock agents and made experimental use of the compounds furnished to them. In one of the tests there, Major R. W. Schroeder made an altitude record of 36,020 ft—nearly 7 miles. His plane was powered by a Liberty engine equipped with one of the first turbosuperchargers.

The use of the antiknock agent in the gasoline was found necessary to prevent knock and preignition under the conditions of charge boost required for the flight. Another use of the aniline-type antiknock agents was in the first non-stop transcontinental airplane flight made by Lieutenants Macready and Kelly during the early 1920's. For them a special fuel containing one of the antiknock agents was prepared for use, especially in the stress of take-off and of gaining altitude when their plane was so heavily loaded with the gasoline required to fly non-stop all the way from New York City to San Diego, California.

Deep Discouragement—and Heartening Discovery

But, as so often happens in the search for new things, the research arrived before long at one of its lowest points. That period of discouragement came about the end of 1920. The practical difficulties with the aniline-type compounds that had to be faced, one of which was their disagreeable odor, gradually made it apparent that the chances of applying them successfully were not bright. Of the odor problem, one of the men wrote, "I doubt if humanity, even to doubling their fuel economy, will put up with this smell." Some members of the group proposed that the search for an antiknock agent be discontinued at that point.

But fortunately, out of the testing of other materials as they became available, an activity that although spasmodic had never been stopped, came just shortly after that time a new and important discovery. A soluble compound of selenium, selenium oxychloride, became available and was obtained. That compound when tested in the engine proved to be very effective as an antiknock agent—considerably more effective than anything tested before that time.

That was a very exciting observation, particularly as it was known from prior work that both the oxygen and the chlorine in the compound would tend to make the knock worse rather than less. So it was thought that selenium in a more suitable combination, one without the handicap of oxygen or chlorine, ought to be much better than aniline. Such a compound, diethyl selenide, was accordingly made, tested, and found to be five times as effective as aniline.

So a compound of tellurium, the element similar to selenium next to it in the periodic table, was made in the form of diethyl telluride. And as an antiknock agent that compound proved to be four times as effective as selenium ethyl, or twenty times as effective as aniline. And that really was exciting. These gratifying discoveries, made all within a few days, naturally lifted the endeavor out of the valley of discouragement into which it had descended and gave it a new lease of life.

But two serious defects were found to apply both to selenium and tellurium. First, a study of availability showed that the potential supply of those two elements was not adequate to treat gasoline on the scale that would be required. And, second, the compounds of both had very bad odors. The most effective of the compounds, tellurium ethyl, smelled like a devilish mixture of garlic and onions. The compound got into a fellow's system and on his clothes so that he carried it with him wherever he went. He could not wash it off, for water only made the odor worse. Nor was the trouble confined to those working directly with the materials. Every one in the whole research laboratory suffered from it to some degree. Things got so bad in that respect that all the secretaries threatened to leave. It happened that Horning visited our laboratory during the time of the tellurium experiments. Afterwards he wrote to Midgley as follows: "This is to let you know that I reached home safely and that everyone is greeting me with gas masks on." For these reasons, the use of tellurium, powerful antiknock agent though it is, was just not practical.

Scientific Fox Hunt

But out of the selenium and tellurium discoveries came an important advance in the method of the investigation. The high antiknock effects of compounds of those elements—when put together with the prior discoveries that compounds of iodine and nitrogen were antiknock agents also, whereas compounds of chlorine, bromine, oxygen, and sulfur were either without effect upon knock or else made knock worse — made us suspect that the antiknock property might be related in a definite way to the positions of the elements in the periodic system. That seemed particularly possible when the results were viewed in the light of a new periodic arrangement of the elements to which we had access. The arrangement was one made by Robert E. Wilson and based upon the Langmuir theory of atomic structure and chemical valence that had been propounded shortly before that time. That periodic arrangement was accordingly made a basis of the search, which thereafter took on more the character which Midgley termed a "scientific fox hunt." The periodic chart pointed not only to the most likely elements to test but also to the valence each element should have in the compound to be tested.

Now that a systematic survey of the relative antiknock effects of similar compounds of a considerable number of the elements was to be undertaken in an effort to determine trends, extensive preparations were made for it in these two respects:

1. By preparing through synthetic means a similar and gasoline soluble compound of each of the several elements to be tested.

2. By developing a means of measuring the antiknock effect more accurately than had been possible before.

In respect to the first item, the principal elements investigated were these eighteen, as arranged in groups according to chemical valence from 1 to 4:

1. Fluorine, chlorine, bromine, and iodine

2. Oxygen, sulfur, selenium, and tellurium.

3. Nitrogen, phosphorous, arsenic, antimony, and bismuth

4. Carbon, silicon, germanium, tin, and lead.

Up to that time compounds had been tested for antiknock effect either by the listening method or by viewing the cards of the Midgley optical indicator, developed meanwhile (7). Neither of those methods was free enough from the human element to be very precise, although in the search up to that time they had served quite well. But for the more exact investigation now to be undertaken, where small differences might be of importance in showing trends, it was thought that a better means of measuring knock was essential.

In the effort to develop such a procedure, various schemes were tried. One of these was a temperature method. It was found though that, in our little air-cooled engine, temperature could not be relied upon to indicate small differences in knocking tendency. Shortly before that time Dr. H. C. Dickinson of the National Bureau of Standards had described a simple device which he had used to detect in a qualitative way whether an airplane engine was knocking. His device consisted of a free pin held loosely in a guide and arranged so that its lower end could be placed on some part of the cylinder head of the engine. When knock was not present that pin merely followed the small flexing of the cylinder head. But when knock was present the cylinder head flexed so violently that the pin was thrown free of its contact. It might in some cases jump as high as 2 in.

We set out to convert that scheme into a quantitative method of measuring knock by comparison with reference fuels. And, without going into the details which have been fully published, the principle was developed during the summer of 1921 into the bouncing-pin indicator (8, 9). That instrument served the purpose for which it was developed in admirable fashion. In the years following it was further refined, and it came finally to be utilized as a part of the improved knock-testing equipment which — thanks in large measure to the assistance of Mr. Horning—was developed cooperatively and has since been used everywhere.

With the newly developed instrument and technique the compounds prepared meanwhile were tested during the fall of 1921. Results were plotted on a peg-board laid out after the fashion of the periodic arrangement already mentioned. The height of the pin inserted in the place of each element tested was made to correspond with its effect on knock, as measured with the aid of the bouncing-pin indicator and by comparison with aniline in a base fuel. From the gradual growth of that peg-board, it soon became apparent that there is a periodic function of the elements in respect to effect upon knock. As the

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work proceeded, it was seen that the pins got longer as they went toward the corner in which lead was placed.

Tetraethyl Lead

An effort to make the ethyl compound of lead, tetraethyl lead, was accordingly begun in dead earnest. An earlier attempt to prepare tetraethyl lead by reacting ethyl iodine with an alloy of sodium and lead had not proved successful. As that method of synthesis had been described in the early chemical literature, when it had been used for making a little of the compound to study its physical properties, our failure was a puzzle to us. But we now turned to another method, also described in the early chemical literature. That method was to make zinc ethyl first and then to react it with lead chloride. Special techniques were required to carry out that method, for when exposed to air zinc ethyl takes fire spontaneously. But it was by that means that a tiny amount of tetraethyl lead was first obtained in our research.

As it turned out, though, only a minute amount of the compound was needed for the determination. For, when tested in the engine by comparison with aniline, which was our reference material then, that tetraethyl lead showed the astonishing antiknock effectiveness of 50 times that of aniline (10, 11). That meant that less than a tenth of one per cent of tetraethyl lead in gasoline had an effect as large as 4 per cent of aniline. This amazing and exciting observation was one of the most dramatic events of the whole program, and it came less than a year after the time when the discouragement was so deep that there was sentiment for dropping the search altogether.

The next thing was to make enough tetraethyl lead to determine whether its use in gasoline was practical. In doing so, we continued with the zinc ethyl method and developed it successfully to a small pilot plant scale. But, not being satisfied with that process for making tetraethyl lead in quantity, further experimenting was done with the method using sodium-lead alloy and ethyl iodide. And after a time the reason for the earlier failure to get tetraethyl lead by that process was found. The method as described in the literature called for digesting an alloy of sodium and lead with ethyl iodide for a time and then extracting the product with ether. That we had done. But it was now found that water for hydrolysis as an intermediate step was required. In the case of the original work described in the literature the need for water had not been mentioned and was perhaps not realized, but the water had been furnished all the same as that naturally present in the reagent ether used for extracting the product. The ether from the laboratory stock which we used however had been dehydrated or dried ether, and thus the needed water had not been present.

So the sodium-lead process of making tetraethyl lead was taken up, and soon it was simplified by substituting steam distillation for ether extraction. With the aid of catalysts that were developed next, it was found possible to subsitute ethyl bromide for the scarce and costly ethyl iodide. Also the aid of the research laboratory of applied chemistry at Massachusetts Institute of Technology, the director of which at that time was Robert E. Wilson, was enlisted in the endeavor. The first effort of the group at MIT was to make the compound tetraisopropyl lead by the electrolysis of a solution of acetone using lead electrodes. That did not prove practical; but afterwards the men there took up a study of the sodium-lead process of producing tetraethyl lead and made a number of valuable contributions to it.

After a time the manufacture of tetraethyl lead was commenced using the sodium-lead and ethyl bromide process, as developed up to that time and further improved in certain respects. Later on the process of making tetraethyl lead was altered by substituting for ethyl bromide the still cheaper ethyl chloride. That modification was made possible by researches conducted for the Standard Oil Development Company by Mrs. C. A. Kraus and C. C. Callis at Clark University.

Many determinations of the effectiveness of tetraethyl lead were naturally made as time went on, and a good many other alkyl compounds of lead were prepared and tested as well. This work brought out such items of information as these.

1. That small amounts of the lead alkyls in gasoline are relatively more effective than larger amounts—that is, that 2 cc of tetraethyl lead per gallon does not have twice the effectiveness of 1 cc.

2. That the magnitude of the knock suppressing effect of tetraethyl lead varies from one fuel to another.

3. That as an antiknock agent tetraethyl lead is generally the most effective of the lead alkyls. Later an extensive investigation of behavior during combustion showed that for a lead alkyl to act as an antiknock agent it must decompose in the hot combustion mixture before the arrival of the flame, and that tetraethyl lead was best in decomposing at the most favorable instant.

Obstacles Appear

Meanwhile in the operation of engines on gasoline containing tetraethyl lead the disheartening discovery was soon made that tetraethyl lead alone could not be used in gasoline. It left solid deposits there, deposits which resulted in serious exhaust valve burning and damage to the insulators and the electrodes of spark plugs. That trouble was not however accepted as an insurmountable obstacle. Instead, an extensive search was begun at once for a means of overcoming the difficulty. The investigation extended over many months and involved during much of that time the running of 12 engines 24 hours a day. It led to the discovery that the trouble could be corrected by adding to the gasoline along with tetraethyl lead an organic compound of bromine, or of bromine and chloride.

But now it was foreseen that, in order to apply that solution in a practical way and on the scale required, it would be necessary to search for new sources of bromine. What little bromine had been needed in photography and for medicinal compounds was readily obtained as a by-product in treating the brine from Michigan salt wells. But this new demand was expected to become so huge that it could not be met with bromine from salt wells.

A survey of other possible sources of bromine was accordingly conducted. Inspection trips were made to the Dead Sea, to Tunisia, and to Mexico. But a domestic source was desired if possible. Unfortunately, there is practically no bromine in our Great Salt Lake, but it was known that bromine is present in the sea. Bromine occurs there however in very, very minute concentration—only 65 parts per million. That means that about ten tons of sea water are required to yield one pound of bromine. Nevertheless, in the face of much skepticism, the problem of getting bromine out of the sea was attacked with courage and vigor. And, after a great deal of intensive effort on the part of all the men in the research laboratory of the Ethyl Corporation and of those in our group, a way was found to do it.

Later, under contract with the Ethyl Corporation, the method was given a full-scale and successful trial by the du Pont Company (12). As a means of avoiding the sediment and the possible fresh water contamination of shore waters, the trial was made at sea on a ship fitted out as a chemical plant

—but with the operating personnel suffering grievously from seasickness. The process as developed then is not the one now in commercial use by the Ethyl-Dow Chemical Company, and by means of which many millions of pounds of bromine are being taken out of the sea each year. But it served the useful purpose of demonstrating that, in spite of the minuteness of the concentration of bromine in sea water, its extraction is practicable.

A third major obstacle was the fear of lead poisoning. From the outset it was appreciated that putting tetraethyl lead into gasoline might possibly introduce a health hazard. The first opinions of the doctors who were consulted were full of such frightening phrases as "grave fears," "distinct risk," "widespread lead poisoning," and the like. The source of the possible hazard to health thought of at first was not so much that from tetraethyl lead itself as that from finely divided lead dust in engine exhaust.

On this question, after preliminary and encouraging experiments of our own, we were fortunate in having been able to arrange with the Bureau of Mines to undertake a comprehensive study of the question. After a good many months of experiments, in which animals in a large chamber were exposed for several hours each day to the exhaust from an engine running on leaded gasoline, they found "no indication of plumbism in any of the animals used" (13). During the period of those tests five puppies were actually born in the chamber, and they spent each day during the remainder of the tests in the chamber, all without harm of any kind.

Of tetraethyl lead itself, however, it was soon discovered that in the manufacture and handling of the concentrated fluid elaborate precautions are necessary to avoid serious poisoning hazards to those working with it. No one had had experience before with poisoning by such organic compounds of lead, the symptoms and the effects of which proved to be quite different from those of lead poisoning of the familiar type. The consequence was that several serious cases of poisoning occurred, some of them fatal, before the character and the strictness of the precautions that have to be taken were understood.

These experiences caused concern also about the health of those handling and using gasoline containing tetraethyl lead, although the concentration present there was extremely small. There developed on the part of some individuals and agencies an intensive agitation to prohibit the use of tetraethyl lead in gasoline. This was so in spite of the experience that there had been no sign of any harmful effect among users of leaded gasoline, which had already been distributed for many months.

At that point a comprehensive investigation of the subject was instituted under the auspices of a committee appointed by Surgeon General Hugh S. Cumming of the U. S. Public Health Service, and consisting of recognized authorities in the fields of medicine, physiology, public health, and chemistry. The purpose was to settle once and for all, and to the satisfaction of everyone concerned, whether the distribution of gasoline containing tetraethyl lead involved any hazard to the health of those who used it or distributed it. Meanwhile the sale of leaded gasoline was discontinued, except where necessary for the investigation.

After some months of intensive study, during which more than 250 persons in five groups, some using or distributing leaded gasoline and some not, were each examined at frequent intervals in an elaborate program of particulars, the conclusion reached was this: That, when its distribution and use is controlled by proper safeguards, there is no hazard from gasoline containing tetraethyl lead (14). Later and still more extensive studies showed again that, when those simple safeguards are observed, "there is no reason to fear the existence of danger to the public health from the distribution and use of leaded gasoline" (15).

When the investigation of the possible health hazards from tetraethyl lead was begun it was believed that lead absorption was completely cumulative. No matter how little lead was taken into the system, it was thought, the person exposed would ultimately accumulate a dangerous amount of it. But, very fortunately, that conception was found not to be true; for, up to a certain critical rate of absorption, the normal excretion of lead was found to be as great as the intake.

This investigation of the possibility of health hazards to users of gasoline containing tetraethyl lead, with its gratifying outcome, ended the long struggle to solve in a practical manner the primary problems relating to the compound as an antiknock agent. This did not mean that research in the field was finished by any means. On the contrary, an immense amount of research has been done by interested groups since that time, and that research is still being pursued in intensive fashion.

Only the major problems have been mentioned in this review of the pioneering work. But there were many minor problems. Just to cite one of these, there was at the outset much difficulty from the instability of tetraethyl lead mixtures. One of those who was given a sample of an early mix, a mixture of composition which proved to be unstable, wrote this to the man who gave it to him:

> "Please tell Kettering for me that the antiknock, in addition to being a good remedy for knocks in motors, is also very effective as a bomb. The bottle you left with me has been standing on my desk ever since you were here, and yesterday while I was telephoning the bottle blew up in my face."

Fuel Structure Investigated

Following the period of work on the chemical antiknock agents, research on the influence on knock of the structure of fuels themselves was taken up in an active way. Because, from the viewpoint of satisfactory and economical utilization in engines, the value of a hydrocarbon fuel hinges wholly upon the structure or architecture of its molecules, the investigations in this field have been of the highest importance. And so the following account of these endeavors — while it cannot be presented without some technicality of terms, and is therefore not the most interesting part of the lecture perhaps — deserves particular attention.

When first undertaken in 1926 this second phase of the research was intended to have a wider scope than studying the knocking properties of hydrocarbons. It was aimed also at getting some more fundamental knowledge of engine combustion, and particularly at getting a better understanding of the mechanism of knock. A small amount of work had already been done in studying the influence of fuel structure on knock, and the results of it had been published (16, 17, 18). Some studies of combustion had previously been made too, both in a bomb and in engines. In a bomb, flame movement had been studied by photographing it through a window on a moving film (19, 20). Also, through a quartz window in the combustion chamber, some measurements had been made of the energy radiated by engine combustion under different conditions and at various times in the cycle (21).

The plan now was to observe the knocking behavior in engines of individual hydrocarbons and also of various oxygen-containing compounds, such as alcohols, ethers, aldehydes, and organic acids, which might be thought of as products of partial oxi-

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dation of hydrocarbons. From the information obtained in that way it was hoped that we might be able in some measure to follow the course of combustion in the engine, and in particular to learn how the mechanism of knocking combustion differs from that of non-knocking combustion.

After this program had been pursued for only a little while, the wide difference in knocking behavior between normal heptane and isoctane was observed, first by Graham Edgar and his associates at the Ethyl Corporation in their search for a better reference fuel for rating the knocking qualities of gasolines than had been available before (22). In view of the large magnitude of those differences in the paraffin hydrocarbons, it seemed desirable to concentrate our program on the hydrocarbons to see just what the ranges of knocking quality are and to determine in as specific a manner as possible how knocking quality relates to chemical constitution.

In addition to the information on knocking behavior of hydrocarbons just mentioned and to the earlier work already referred to (16, 17, 18), H. R. Ricardo had published results of investigations of 13 individual fuel compounds, of which 8 were hydrocarbons, to determine the "highest useful compression ratio." He too had observed considerable differences in knocking tendency, depending upon chemical composition (23).

In our study determinations of the knocking properties of the hydrocarbons were made at first in fairly dilute solution in a base gasoline and by comparison with aniline as a reference material in the same base gasoline. The method of rating in solution was adopted primarily to extend the range of compounds that could be tested, some of which could be made available only in very small amounts.[1] Samples of the hydrocarbons tested were obtained chiefly by synthesis in our own laboratory, but some by purchase, and some by donation of a number of those working in the hydrocarbon field. Samples of all the 9 isomeric heptanes, for instance, were donated by Graham Edgar, and a few of the olefins by Frank C. Whitmore of Pennsylvania State College.

By this means the knocking behavior of 171 hydrocarbons — 27 paraffins, 15 olefins, 70 saturated and unsaturated naphthenes, and 59 aromatics — were measured and the results published (25, 26, 27, 28). The data showed not only wide differences in knocking behavior, but also a number of regular and consistent relationships between tendency to knock and molecular structure, such as the following for paraffin hydrocarbons:

1. That tendency to knock increases at a rapid rate with lengthening of the carbon chain.

2. That the addition of methyl groups as side chains raises freedom from knock in a consistent fashion.

3. That the more closely compacted the carbon structure the better, and that the most closely compacted paraffin hydrocarbons are very good in degree of freedom from knock.

While this work was in progress some other investigators also made measurements of a number of individual hydrocarbons in solution in a base fuel. These workers included Nash and Howes (29); Birch and Stansfield (30); Garner, Wilkinson, and Nash (31); and Garner and Evans (32). Comparison of all the ratings for similar compounds made by the different investigators, while not obtained under equivalent conditions, nevertheless showed a sufficient degree of agreement to establish confidence in the data.

The next phase of the research was determining the knocking characteristics of individual hydrocarbons alone —that is, not as before in solution in a base gasoline. In this study measurements of knocking characteristics were made in terms of critical compression ratio[2]. A paper giving such data on 103 hydrocarbons—paraffins, olefins, naphthenes, and aromatics—was presented in 1934 (33). The critical compression ratios of the hydrocarbons included were found to vary over a range of about 14 ratios. Some thus permitted very high engine compressions without knock.

The general correlations between knocking characteristics and molecular structure previously found for such hydrocarbons when rated in dilute solution in a base fuel held for these data also. There were, however, some important exceptions. These arose from the observed fact that the knock behavior of mixtures does not vary in the same way with concentration for every hydrocarbon.

This work on the knocking behaviors of the hydrocarbons themselves was extended by determining also for many of them the effectiveness of additions of tetraethyl lead for boosting degree of freedom from knock (34). Results showed that the effectiveness of tetraethyl lead varies widely depending upon the structure and properties of the hydrocarbon in which it is used. It was found, in fact, that degree of effectiveness of tetraethyl lead may run all the way from a very high positive or knock-suppressing effect to a considerable negative or knock-inducing effect. Fortunately, effectiveness is highest in the types of hydrocarbons that make the best fuels. In respect to the part which luck plays in research, by the way, just suppose that the first test of tetraethyl lead had chanced to be made not in gasoline but in one of those fuels in which it is not a knock suppressor!

Cooperation Extends Hydrocarbon Research

The results of all these studies of the relationship of knocking behavior to hydrocarbon structure have since been greatly extended and improved by the work done under the cooperative endeavor begun in 1938 and conducted as American Petroleum Institute Research Project 45. The tabulation of the results of that important endeavor now "covers more than 325 hydrocarbons and includes original and derived data on the compounds both straight and blended, with and without tetraethyl lead" (35). And the project is still going ahead.

The principle deficiency of data on the knocking behavior of individual hydrocarbons obtained prior to this program was that for the most part ratings were made under only one set of engine operating conditions. The result was that there was little quantitative knowledge of the property of hydrocarbons that has come to be called sensitivity. But in the program under Project 45 this deficiency in rating procedure has been corrected. While the ratings, most of them, are still made in the same engine used in the earlier investigations reported above, they are now made under a variety of conditions of engine speed, jacket temperature, and other variables. On a considerable portion of the hydrocarbons data have been obtained under conditions of supercharge operation also. The hydrocarbons prepared for this program, the majority of which have been synthesized at The Ohio State University, have cost between a thousand and two thousand dollars a gallon, and they have been mighty cheap at the price.

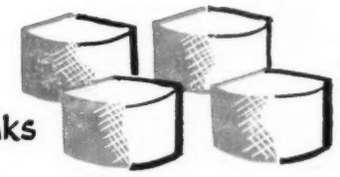
The worth of the knowledge gained from all the research conducted in this field during the more than 20 years past is so extremely large that it perhaps cannot be computed.

[1]The apparatus used was a one-cylinder, variable compression engine, evaporatively cooled. It was fitted with the bouncing-pin indicator and was run at 600 rpm without heat on the mixture (24).

[2]Most of the hydrocarbons tested in this phase of the program also were synthesized in our laboratory, but a few were obtained from commercial sources, and some were supplied by persons working in the hydrocarbon field. The engine used was, as before, one-cylinder, variable compression, evaporatively cooled, running at 600 rpm and without heat on the mixture. Determination, of the compression ratio for borderline knock, was by ear.

Easy Lesson in CONSERVATION ECONOMICS

If you have several cone roof tanks



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and filling losses

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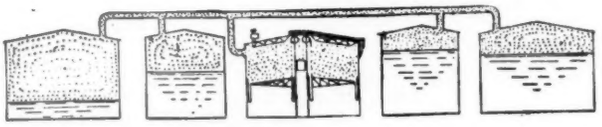

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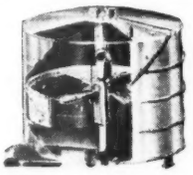

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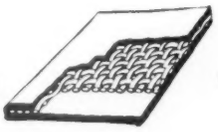

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Through what all it has done to stimulate catalytic cracking, polymerization, isomerization, alkylation, and other new forms of petroleum processing, it has helped to bring about the modern revolution in petroleum refining with the better products resulting from it. In addition to the immense value of the knowledge in peacetime, it was of the greatest usefulness in the Second World War, when it formed the very keystone of the high octane aviation gasoline program. The important table of knocking properties assembled in that research was the bible of the men who had to do with the procuring of aviation gasoline.

It has been estimated that, in all, 70 per cent of the high octane aviation gasoline used in the Second World War was composed of hydrocarbons made by synthetic methods (36) — hydrocarbons found in these researches to be good in degree of freedom from knock. The synthetic molecules were made mainly by two means: First, by the method of synthesis called alkylation, operated on a huge scale; and, second, by catalytic cracking. The superior aviation gasoline obtained by blending these products and then adding tetraethyl lead permitted the airplane engine in the Second World War to give four times the output obtained from one of the same displacement in the First World War.

Triptane

One of the hydrocarbons that was early found to be among the highest in degree of freedom from knock—its superlative effectiveness was first observed in 1926—was the heptane, 2, 2, 3-trimethyl butane, which after a suggestion by George Calingaert came to be called triptane for short. When early in the Second World War those in charge of the aviation fuel program made known a desire for a method of manufacturing triptane as a possible component of aviation gasoline, an effort was made in our laboratory to develop a practical process for it. The hydrocarbon had previously been made, in the amount of 300 gal, by the Dow Chemical Company for the Ethyl Corporation; and, in full scale aviation engine tests at Wright Field, it had been found superior in power potentialities to any other fuel tested up to that time. The method employed in making that triptane was the well known Grignard reaction, which was not suitable for use on any considerable scale.

In our research a better process of making triptane was found. It consisted in methylating the olefin, trimethylethylene, with methyl chloride in the presence of lime and then hydrogenating the product (37). In a large-scale pilot plant built for the purpose, triptane was produced, several tanks cars in amount (38).

The product was subjected to extensive tests, chiefly by the Aircraft Engine Research Laboratory — now the Lewis Flight Propulsion Laboratory—of the National Advisory Committee for Aeronautics (39, 40). The performance number of triptane plus 4 cc tetraethyl lead per gallon, measured by the F-4 procedure (A.S.T.M. D-909), was found to be 360 (40). This means that in a supercharged engine it is capable of giving 3.6 times as much power as the 100-octane reference fuel, iso-octane. The temperature characteristics of triptane were observed to be such that for high output in airplane engines it requires inlet-air temperatures that are relatively low. But, with suitable control of inlet-air temperature, triptane makes possible very high engine powers. Alternatively, with a boost in compression ratio instead of in degree of supercharge, it can give a considerable improvement in airplane fuel economy.

High Compression

When the war came to an end there remained a stock of triptane, along with certain other high-octane hydrocarbons obtained as by-products in the process, and more could be produced as required. Advantage was taken of that circumstance to make a more thorough and extensive evaluation of the benefits of high compression, or to find out just what is the maximum efficiency that can be got in the automobile engine, provided a fuel completely free from knock is available. Triptane, with the addition of small amounts of tetraethyl lead, is such a fuel.

A single cylinder engine was first built to explore the range of compression ratios from 6 to 1 up to 15 to 1. The tests on that engine, using triptane as fuel—although it was found to be freer from knock than was required—gave the basic data for designing and building a multicylinder engine of 12.5 to 1 compression ratio which could be installed in a car. That engine was designed according to rather conventional procedures, except that it was made rigid enough to carry the higher loads involved. And those loads were very large, as may be known from the fact that the explosion pressure was more than 1000 psi, or more than 10,000 lb on the top of each piston. Two things that helped greatly in doing that were our wide diesel experience and the results of an extensive prior study of the causes of roughness in the gasoline engine (41, 42).

Experience with the engines thus obtained, and having a compression ratio of 12.5 to 1, has shown that, with performance matching that of existing automobile engines, they give an average increase in miles per gallon of at least a third. Also — and contrary to the expectations of many — those engines are smooth or free from roughness, they are high in mechanical efficiency, and they do not require fuels more free from knock than the best of those being made from petroleum by existing refinery processes (43, 44). The utilization of this important knowledge, when it can be fully realized in a commercially practicable manner, will represent another long step forward in the fitting of fuels and engines for maximum usefulness.

Combustion Studies

There remains to be mentioned in this tabloid review one other important phase of the long research. This is the part of it devoted to learning what could be found out about the mechanism of combustion in the gasoline engine. Because the whole usefulness of the automobile depends upon what happens when gasoline burns in the engine, it is important to learn as much as possible about it. Some of the early work in this field has already been mentioned: That devoted to photographing on a moving film combustion events in a bomb (19, 20), and that concerned with measuring the energy radiated by engine combustion (21). We had also investigated combustion in tubes.

The further effort to study combustion events—events that are not easy to investigate because they take place inside an engine and all within the hundredth part of a second or less—have made use of many aids to observation, and have included the following endeavors:

1. Snatching samples of gas at selected times in the cycle and determining their compositions by chemical analysis. Samples were withdrawn by means of an auxiliary valve that could be situated at any one of several places in the ceiling of the combustion chamber and opened for extremely brief intervals at any time desired (45).
2. Photographing the progress of the flame as it proceeded from the spark plug to the end of the combustion space, and obtaining also a simultaneous pressure record. By means of a special camera photographs were taken on a moving film through a narrow quartz win-

dow extending the full length of the combustion chamber, and simultaneous pressure records were obtained with an indicator (46, 47).

3. Comparing the frequency of pressure surges in the burning charge with that of the sound of knock. This was done by means of an engine indicator and a microphone, each connected to a cathode-ray oscillograph, the screens of both of which could be photographed simultaneously (48).
4. Dissecting the light from engine combustion by means of a spectroscope to determine the composition of the gases within the flame and behind it. The spectroscope was trained on a narrow quartz window extending the full length of the combustion chamber. The particular area to be examined was isolated and the observation timed by means of a stroboscope (49, 50).
5. Studying changes in composition of the non-luminous charge ahead of the flame by determining with a spectroscope the discontinuities which resulted from absorption of light frequencies within the charge. This was done through windows on opposite sides of the combustion space, with a light of continuous spectrum in front of one window and a spectroscope in front of the other (51, 52, 53).
6. Measuring the temperature of the inflamed gases in the engine. This was done through windows on opposite sides of the combustion space, with a tungsten-filament lamp, the temperature of which could be varied at will within known limits, in front of one window and a spectroscope in front of the other. With a trace of sodium in the charge, the temperature of the lamp filament at which the sodium line reversed in the spectroscope from a bright line of emission to a dark line of absorption was determined (54).
7. Making high-speed motion pictures of knocking and non-knocking engine combustion. From these records and simultaneous pressure cards, volume of charge inflamed was related to mass burned and mass burned to pressure developed. The pictures were taken through a quartz window forming the entire ceiling of the combustion chamber by means of a specially constructed camera arranged to take 30 successive pictures at 2.4 deg. intervals of events during the burning of a single charge, while a simultaneous record of pressure changes was made by means of an engine indicator (55, 56, 57, 58, 59, 60).[3]
8. Studying the possible place of free radical chain reactions in the combustion of hydrocarbons. The reactions with representative hydrocarbons of free radicals—resulting from the decomposition of tetraethyl lead and other substances—were studied and correlated with the knocking characteristics of various hydrocarbons (61, 62).

Just a few of the items of knowledge that have come out of these several efforts to pry into the secrets of combustion are the following:

1. The rate at which flame travels through the charge following ignition increases with engine speed, and just about in proportion to it. It is this fortunate circumstance which makes it possible to run gasoline engines at very high speeds.
2. The combustion of fuel completes itself within the narrow moving band which may be considered as the flame front.
3. Knock is accompanied by, or is preceded by, self-ignition of the charge ahead of the advancing flame front. Following such formation of fire out ahead of the normal flame, that final portion of the charge is consumed with extreme rapidity.
4. The chemical changes that occur within the zone of charge ahead of the flame to produce the self-ignition causing knock are far from being fully understood, but one of the compounds formed in the process is formaldehyde.
5. The extremely rapid combustion of the final part of the charge when knock occurs generates abnormally high pressures in the engine. It may also produce violent pressure waves within the hot gas. Those pressure waves have exactly the same frequency as that of the metallic sound of knock which is heard outside, and the frequency varies with the dimensions of the combustion space and with the temperature of the gas.
6. The highest gas temperature in the burning charge is not in the flame front itself, but in the luminous gas behind the flame. This is equivalent to saying that the highest temperature is not in the fire but in the ashes. That apparent paradox is believed to be explained by the further compression of the hot gas behind the flame as the burning of the charge progresses.
7. The temperatures reached within the gases during combustion are extremely high—over 4000 deg F; and, in the case of knocking combustion, about 4500 deg. The latter temperature is higher than the *boiling point* of iron.
8. There is a definite relationship between volume of charge inflamed and mass burned and between mass burned and pressure developed, when piston motion has been taken account of. This means that, when accurate pressure cards can be obtained, those relationships can be derived directly from pressure cards.

[3]It was for their paper in 1938, reporting a part of this research (Ref. 58), that the first Horning Memorial Award was made to Gerald M. Rassweiler and Lloyd Withrow.

Conclusion

Finally, it must recognized that all these investigations of fuels and how they burn in engines, although fairly extensive in scope, have not yet yielded a thorough understanding of the subject. They have produced no explanation of why the structure of a hydrocarbon influences the way it burns in respect to knocking behavior, of why an antiknock agent exerts the remarkable effect it does, nor of many other factors. Fact is that we are still a long, long way from having attained a complete understanding of what happens when fuel burns in the gasoline engine.

The incentive for further research on fuels and engines is far greater than merely that of advancing the knowledge of the subject. It rests on the base of the huge economic gains realized out of the investigations conducted thus far, and on that of the similar benefits still in prospect. Just since 1930 the efficiency of the average automobile engine, measured in ton miles per gallon, has been boosted by 30 per cent or more (44). On the huge gasoline bill of the nation today, that improvement represents a yearly saving to the public of more than two billion dollars. In terms of conservation of our valuable resources of petroleum, that same saving represents all the gasoline to be obtained from the output of about 1500 oil wells each producing a thousand barrels per day. Furthermore, as has been shown in the recent research on still higher compression automobile engines reported above, there is at least another 30 per cent gain in economy to be had, whenever the fuels required for it can be provided in a commercially practicable manner. And even this is probably not the end at all. These are the considerations that justify the continuation of vigorous research on fuels and engines, the quest and conquest which it is the purpose of the Horning Memorial Award to help stimulate.

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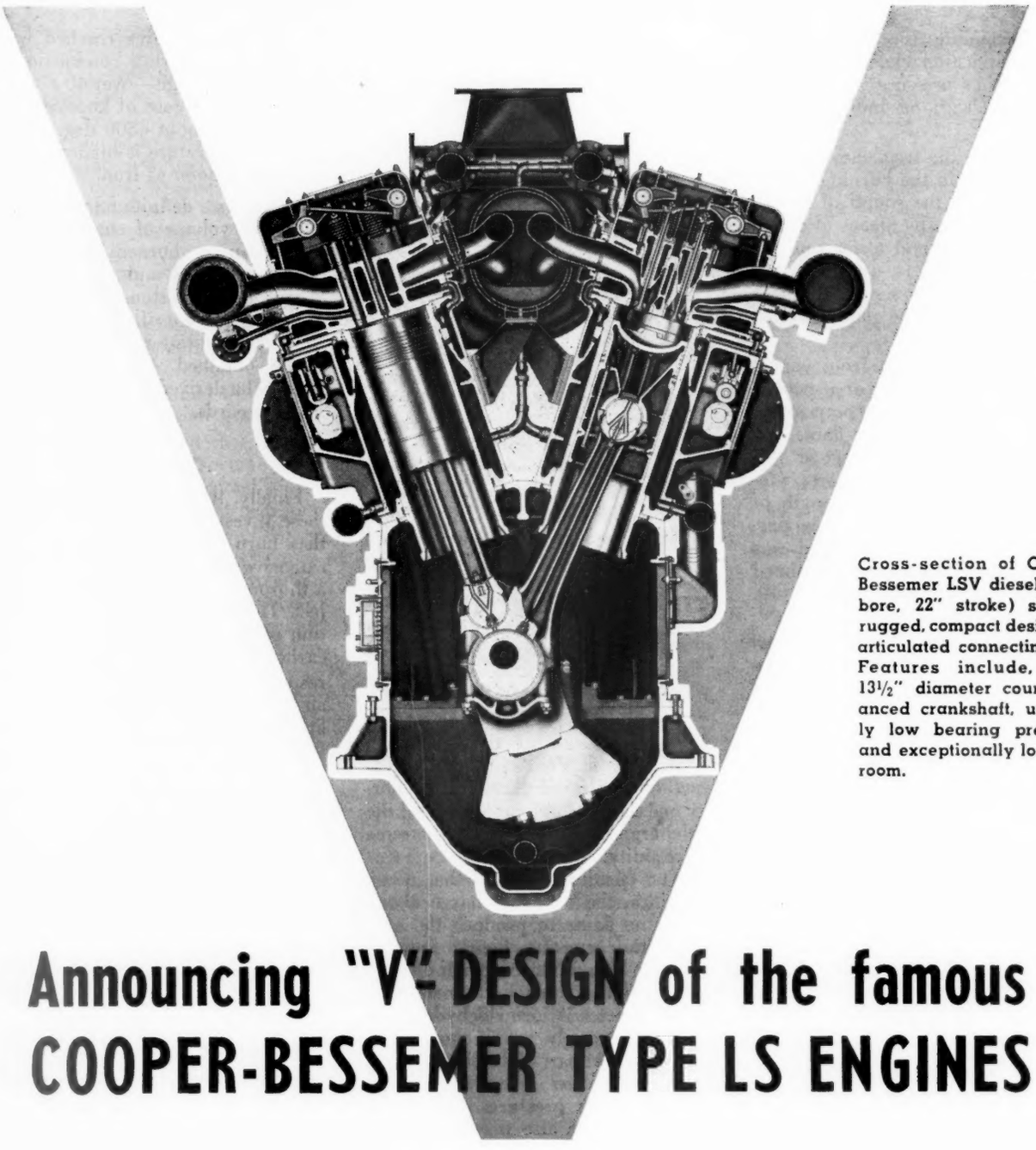

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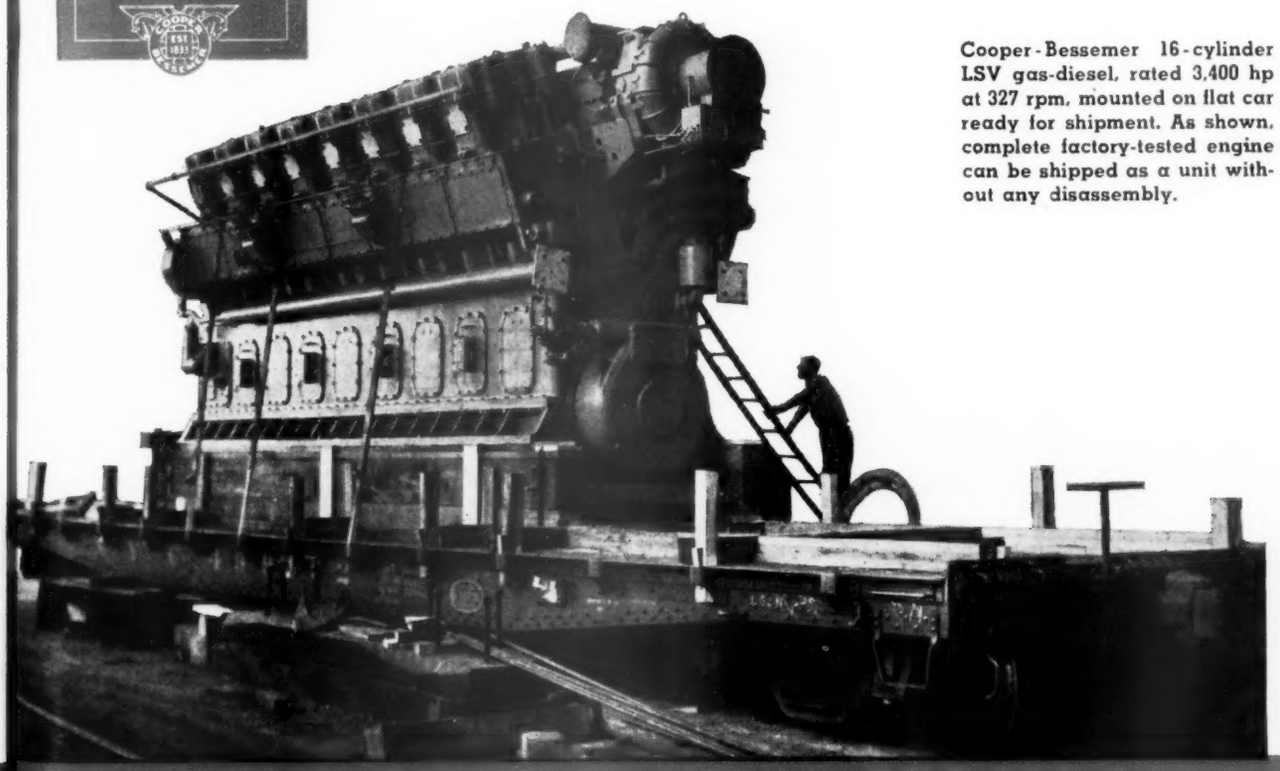

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★ ★ ★

In 1940 there was . . . *1*

In 1944 there were . . . *215*

In 1948 there were . . . *500*

and as of May 1950 there are more than

652

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Have Oil Imports Influenced Drilling?*

Standard of California's Board Chairman Maintains That Imports Have Not Endangered Sound Condition of Domestic Industry

R. G. FOLLIS†

I WELCOME the opportunity to appear before your Commission to present statistics which, it is hoped, may contribute to a continued, sound solution of your problems in determining allowables for future oil production.

You have asked us to estimate as best we can the amounts of crude oil, gasoline, and heating oil that will be necessary as of two specific dates to fill this country's pipe lines and to provide adequate storage and ample working stocks. Our estimates for the United States are as follows:

Total barrels	April 1, 1950	September 1, 1950
Crude oil	250,000,000	250,000,000
Gasoline	125,000,000	105,000,000
Distillates*	35,000,000	70,000,000

*(Includes heating oils other than residual fuel.)

These necessary stock levels have been estimated by observing actual low levels that were attained in recent years, altered by subsequent demand trends and seasonal requirements for the particular products involved.

The foregoing figures for crude oil are the same for both periods. Although refinery demand for crude varies seasonally, crude supply has been made available currently to meet these variations, making unnecessary seasonal accumulations of crude. It should also be pointed out that the September estimate on distillates assumes normal weather next winter; any variance therefrom could make such stocks either inadequate or excessive.

As to anticipated imports of crude oil by domestic subsidiaries of Standard Oil Company of California, it is expected these will average 25,000 bbl a day of refinable crude and 8000 bbl a day of special asphalt crude for the last 6 months of 1950. The special asphalt crude arrives in greater quantities during the summer paving season and in smaller quantities later in the year, but over the 6 months we expect to have total average crude imports of 33,000 bbl daily.

Our total crude requirements are 421,000 bbl a day. To meet these requirements we utilize 237,000 bbl of our own production, 151,000 bbl of domestic purchases from many independent companies, and 33,000 bbl of imports. Our imports represent about 8 per cent of our total requirements. On the other hand, our total exports (excluding Alaska and Hawaii) during the last half of 1950 are expected to be 43,000 bbl per day, or 10,000 bbl a day more than we import.

If imported crude oil were curtailed, the advantages desired from such a step by the domestic producers would be largely nullified in our case because the pressure to preserve American-owned foreign concessions would tend to force the use of these crudes to supply our export market directly. Furthermore, any shift in this direction would be most undesirable from the viewpoint of the domestic refining industry.

We have consistently taken the position that imports of petroleum should supplement, but not supplant, the production of a sound and healthy domestic oil economy. Our nation's military security is dependent upon its long-range reserve position, which can best be protected through the development of world oil resources by United States nationals and through the preservation of our domestic reserves by reasonable use of foreign reserves. We believe that imports should not be restricted by legislative action unless there is evidence that the industry is no longer able to carry on the vigorous and aggressive program of exploration and development which is necessary if it is to meet the nation's requirements in peace or war.

We realize that curtailing large quantities of crude has had a material economic effect on some segments of the industry. Nevertheless, as a result of the magnificent job that state regulatory bodies, particularly your Commission, have done, we have discovered no evidence that the sound and healthy condition of our domestic oil industry as a whole has been endangered by the current volume of imports. For a number of months repeated statements have been made that the high level of imports has discouraged exploratory and drilling activity in this country, thereby endangering our future national security through failure to continue to develop sufficient reserve capacity for use in an emergency. I have before me some recent and authoritative figures that contradict such statements.

The official weekly drilling statistics of your Commission for the week ending May 6, 1950 show that in 1950 to date, compared with the same period in 1949, new oil fields discovered in Texas increased by 23 per cent, the number of oil wells completed by 19 per cent, and the number of drilling applications by 24 per cent. Looking at the same period in 1949 compared to 1948, we find that similar large increases had occurred.

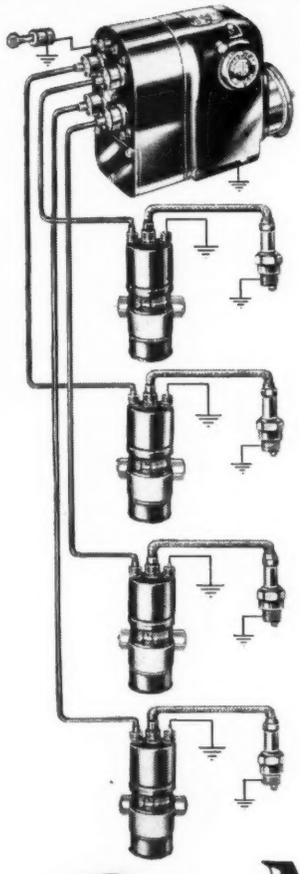
For the country as a whole, numerous statistics are available that show a similar upward trend. According to a report prepared by the American Association of Petroleum Geologists on exploratory drilling in the United States, a summary of which appeared in the April 1950 issue of *The Petroleum Engineer*, 9058 exploratory wells were drilled in this country during 1949, compared with only 8013 during 1948—a gain of 13 per cent. In the preceding year of 1947, only 6775 such wells were drilled.

According to the April 1950 edition of *World Oil* there were 6176 well completions in the United States during the first two months of 1950, compared with only 5536 during the same period of 1949—an increase of almost 12 per cent. The footage drilled in these wells increased by 15 per cent. The number of wells drilled in the corresponding 1948 period was approximately the same as in 1949.

The above statistics are persuasive evidence that the expressed fears concerning reduced exploration and drilling activity as a result of imports are not well founded. It has now been well over a year since your Commission started to reduce allowable production, and it would appear that ample time has elapsed to determine whether incentives to explore and drill for oil have been diminished as a result of imports. The fact that exploration and

*Statement before the Oil and Gas Conservation and Proration hearing of the Texas Railroad Commission, Austin, Texas, May 17, 1950.

†Chairman of the Board, Standard Oil Company of California.



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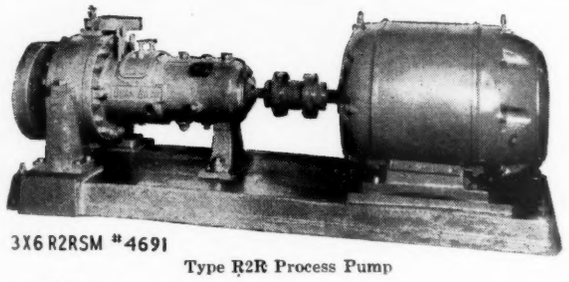
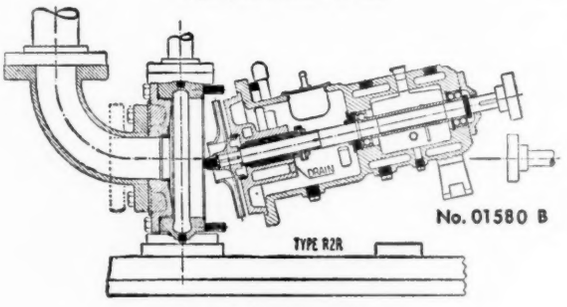
Type R2R Centrifugal Process Pumps



Type R2R Process Pump



Type R2R Process Pump

DISASSEMBLY: The Type R2R process pumps can be disassembled without disconnecting the suction and discharge piping. By first removing the spacer from the spacer type coupling, and unbolting the casing from the cradle the entire cradle and complete rotating element can be removed without disturbing the suction and discharge piping.

OPERATING RANGE: Type R2R, Heavy duty, process pumps are available in eighteen different sizes, enabling our engineers to furnish units specially designed and constructed for the particular work to be performed.

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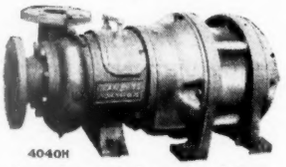
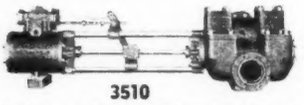
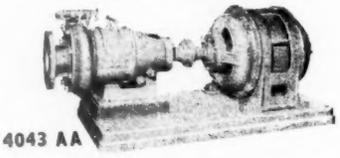


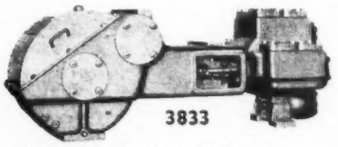
Close Coupled Centrifugal Pump



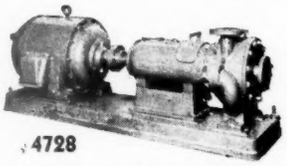
Horizontal, Single Style, Double Acting, Piston Type, Close Clearance Pump. Designed to handle volatile liquids



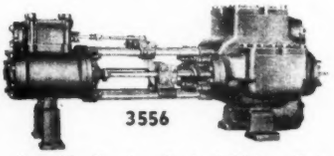
Pedestal Mounted Centrifugal Pump



Horizontal, Duplex, Double Acting, Side Pot, Piston Type, Oil Bath Power Pump



Double Pedestal Bearing Centrifugal Pump



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drilling have increased by the considerable percentages shown above refutes the arguments of those who have been insisting that such activity has been dangerously curtailed.

Here in Texas our subsidiary, Standard Oil Company of Texas, is actively searching for crude and developing its reserves. This year it expects to invest over $15,000,000 in exploratory and development programs and to complete an average of more than 10 wells a month. It is producing approximately 30,000 bbl a day in Texas from more than 30 fields. In addition to this production, our East Coast subsidiaries are purchasing and shipping out of Texas more Texas crude oil than ever before in their history. Currently, this amounts to 16,700 bbl daily as compared with 7700 bbl daily in 1949.

During the past 5 years, the number of persons employed by Standard of Texas has increased 50 per cent, its payrolls have more than doubled and its capital expenditures have more than trebled.

On the other hand, over the past few years our expenditures in Venezuela have decreased from $26 million in 1948 to $17 million in 1949, and to $6 million this year. The number of employees has gone from 1304 in 1948 down to 347 in 1950. Likewise, the capital expenditures and employment of our Middle East affiliates have declined sharply.

In summary, let me repeat that the amount of oil that Standard Oil Company of California expects to import during the last half of 1950 is a very small fraction of its total requirements. Our anticipated imports are only about 4 per cent of the present level of total imports. Furthermore, our imports are more than offset by exports of crude and products to our foreign affiliates and others. From the evidence available to date, imports have not impaired the ability of our domestic oil industry to maintain vigorous exploration and development activities. Moreover, in view of the economic and other factors which control their policies, we find it difficult to believe that domestic oil companies will increase their imports to the point where they will adversely affect this situation. We believe that the complex and difficult problem of imports can best be solved by voluntary action on the part of the industry. In our opinion, the imposition of legislation designed to control imports would establish a dangerous precedent and lead ultimately to federal control of the entire economic status of an industry, which so far has remained relatively free of federal regulation. ★ ★ ★

Equipment and Techniques for 20,000-Ft Drilling

Problems connected with deep drilling are studied by API group.

JOHN M. PAYNE*

THE never-ending search for new petroleum reserves has necessitated drilling to increasingly greater depths, and, with oil now being produced from below 15,500 ft, it seems inevitable that the need for 20,000-ft commercial drilling will develop in the near future. Many equipment limitations already have been reached in drilling the record wells of today, and it is becoming more and more evident that deep drilling is an exact science for which the equipment must be carefully engineered if it is to do a specific job. Although one rig has successfully drilled to more than 20,000 ft in one locality, drilling in different localities, as well as completing a well at that depth — all within a reasonable amount of time and expense — may offer a large number of problems that as yet have not been solved.

This paper reports the findings of a study group on deep drilling, a study conducted under the auspices of the Houston Chapter of the API Division of Production; 16 meetings were held during a period of 6 months, and more than 150 representatives of the users and suppliers of oil-field equipment and services attended and participated in the study. Eight co-chairmen, consisting of a user and supplier for each of four main topics, presided over the meetings, and they were responsible for the development of the information presented herein. The object of this study was not necessarily to solve all the problems connected with 20,000-ft drilling but, rather, to find out what problems do exist in order that they may be referred to specialists in the respective fields for detailed study and development.

TUBULAR GOODS

The selection of drill pipe and casing is one of the most important considerations involved in the investigation of 20,000-ft drilling. Their sizes and weights must first be determined as a basis for hoisting loads, pump requirements, rotating loads, hole sizes, and many other related factors.

Casing

Before the casing strings can be designed, the conditions to be encountered at depths of 20,000 ft must be carefully considered; and the design must be such as to allow for the extremes that might be anticipated. The subsurface pressure is normally taken to be ½ psi per foot of depth; the maximum abnormal pressures might be equal to the weight of the overburden, which is 1 psi per foot. A recent completion in the Mississippi Delta is producing oil from a depth of 13,000 ft, with a calculated bottom-hole pressure of 12,635 psi based on the flowing tubing pressure of 7900 psi. The temperature gradients vary for different localities; however, abnormal temperatures amounting to a 2.2 F rise per 100 ft is considered the maximum that should be ecountered; i.e., about 500 F at 20,000 ft.

The mechanical factors that were considered in designing casing strings for 20,000-ft wells are as follows:

1. *Bursting Strength.* Calculations are based on Barlow's formula:

$$P = \frac{2ST}{D}(0.875)$$

Where:

P = internal yield, psi.
S = minimum yield strength of steel, psi.
T = wall thickness, in.
D = outside diameter of casing, in.
0.875 = the percentage of values given in *API Code 5-C-2.*

This formula is considered usable, inasmuch as the error is always on the safe side, and the deviation is small.

2. *Collapse.* For the purpose of this study, the present API collapse formulas are sufficient, but considerable revision is needed for high yield-strength steels.

3. *Tension.* It is agreed that 100 per cent joint strength is required, and this was used for making the designs. One company has a cold-worked modified API joint that will give this desired result.

4. *Buoyancy.* This factor was neglected.

5. *Bi-Axial Stress.* Inasmuch as the lower portion of a string of casing when run into a hole is in compression (as proved hereinafter), it is shown that collapse resistance is not lowered below the neutral point. Above the neutral point, actual collapsing pressures have been reduced to a point where the effect of tensile forces on collapse resistance of the casing is not critical. Inasmuch as buoyancy was neglected, it was deemed unnecessary to apply bi-axial loading correction.

The following is offered as proof that the lower portion of a tubular string that is suspended in a liquid is in compression:

Fig. 1 has been drawn for assistance in finding the neutral point. In explanation, assume the string to be composed of staggered sections, as shown in Fig. 1. The neutral point is at **m—n** at some distance x above the top of the nth section. For simplicity, assume all sections have the same length **H.**

The net downward force (weight less buoyancy) for each section is:

$$(d-w)\,A\,H$$

Where:

A = cross-sectional area.
d = density of the steel.
w = density of the mud.

The sum of the net downward forces for the n sections below m—n is then:

$$n\,(d-w)\,A\,H$$

The weight of the section x also acts downward, and is equal to $x\,A\,d$.

The upward force in equilibrium with the total downward forces is the hydrostatic force F_n, which is equal to:

$$A\,(L-n\,H)\,w$$

where: L is the depth to the bottom of the string.

Equating the upward and downward forces:

$$A\,(L-n\,H)\,W = n\,(d-w)\,A\,H + x\,A\,d$$

Rearranging:

$$L\,w = (n\,H + x)\,d$$

But $n\,H + x$ equals y equals distance of the neutral point above bottom.

Solving for y:

†Presented to a Division of Production Group Session during the 29th Annual Meeting of the American Petroleum Institute, in the Stevens Hotel, Chicago, Illinois, November 8, 1949.

*Shell Oil Company, Kilgore, Texas.

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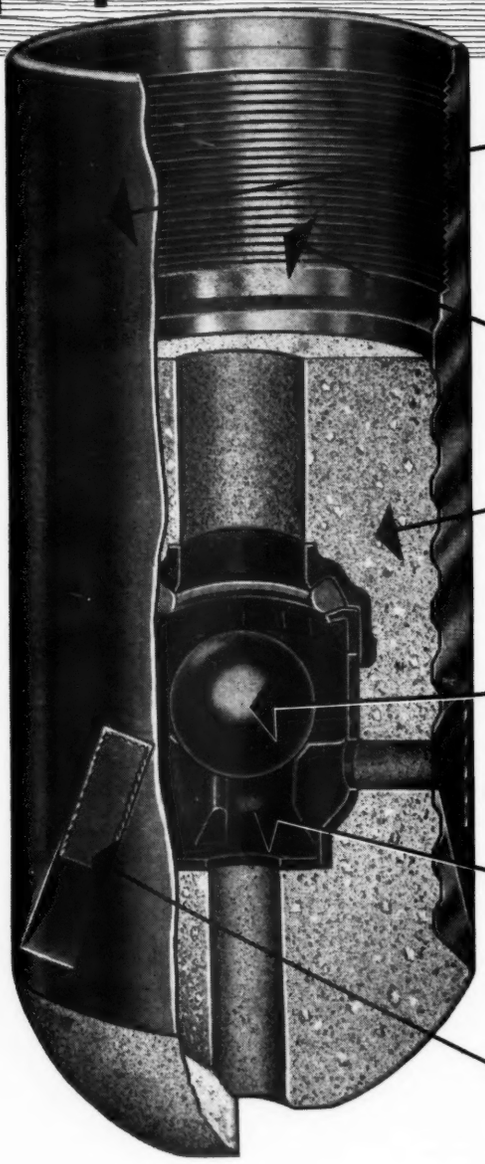

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PLASTIC BALL VALVE to seal instantly against a resilient valve seat

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Whirling **ON CENTER IS THE**

$$y = \frac{L\,W}{d}$$

which is the same result obtained for a straight string. Each of the sections below the neutral point is in compression, because the tension load applied by the effective weight (weight less buoyancy) of the sections below it is insufficient to offset the compression load produced by the pressure, which acts on the free ends.

It is illuminating to consider this matter from another viewpoint, as illustrated in Fig. 2. This shows a string connected by links, or chain, etc., which leaves a space between the sections so that pressure has access to the ends. In this respect, this structure is similar to the staggered string. Now it is seen that the hydrostatic forces F_1, F_2, etc., occur in pairs that are equal and opposite, so that in a summing up of the vertical forces they cancel out. Further, this structure would have a neutral point in a continuous length of pipe. It does not make any difference how the sections of pipe are assembled: the neutral point exists, and it is always at the same place for a given depth and weight of mud. In fact, we have, in threaded and coupled casing, a situation something similar to Fig. 2. The ends of the pipe inside the coupling are acted upon by hydrostatic forces, but they merely set up counteracting forces in the J distance of the coupling. They have no effect on the existence or location of the neutral point.

6. *Temperature.* No ill effects on the strength of the steel are anticipated from bottom-hole temperatures as high as 500 F.

7. *Surface Pressure.* For purposes of design, a pressure gradient of 1 psi per foot of depth was used; i.e., 20,000 psi at 20,000 ft as abnormal pressure. The maximum surface pressure under these conditions would be approximately 14,000 psi.

By using the factors as outlined hereinbefore, the following casing designs were developed:

1. *20,000-ft 5½-in. casing string (oil).*

Based on—

110,000 psi minimum yield strength; 115,000 psi average yield strength; and 120,000 psi ultimate yield strength.

100 per cent joint strength (tension safety factors based on pipe-wall strength.)

Not corrected for bi-axial loading.

Safety factors: 1.125 minimum in collapse, and 1.9 minimum in tension. Salt water was used in calculating the safety factors.

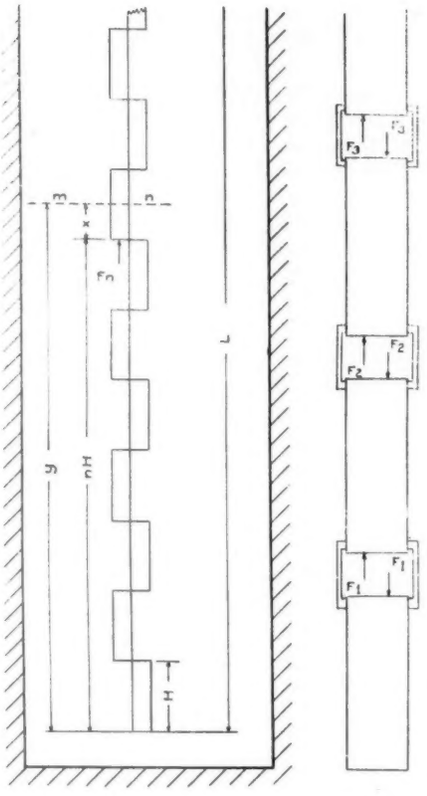

FIG. 1 FIG. 2

Suspended tubular string.

Bursting strength: 14,000 psi or better, unless otherwise noted.

2100 ft—23 lb (top)
2500 ft—20 lb
9500 ft—17 lb (ultimate in bursting, 13,300 psi)
4000 ft—20 lb
1900 ft—23 lb (bottom)

. . . overall weight 385,200 lb

2. *20,000-ft 7-in. casing string (oil).*

Conditions same as for 5½-in., except that safety factor for tension was raised to 2, which is considered the desirable minimum:

1150 ft—38 lb (top)
1350 ft—35 lb
1500 ft—32 lb
1700 ft—29 lb
7000 ft—26 lb (ultimate in bursting, 12,400 psi)
2600 ft—29 lb
2400 ft—32 lb
2300 ft—35 lb (bottom)

.....overall weight—602,950 lb

3. *13,000-ft 9⅝-in. casing string (intermediate).*

Conditions same as for 7-in.

8400 ft—43.5 lb (ultimate in bursting, 10,850 psi) (top)
1900 ft—47 lb
2700 ft—53.5 lb (bottom)

.....overall weight—599,150 lb

4. *7000-ft 13⅜-in. casing string (surface).*

Conditions same as for 7-in., except yield strength.

In the design of this string, the limits were defined by the $\frac{D}{t}$ ratio that must, regardless of yield strength, fall at or below the value 23.232. Any value above this figure will fall beyond the limits defined by the elastic curve. Grade N-80 steel will suffice for a 7000-ft string, as follows:

A plain-end weight of 78.736 lb was established, this weight having a wall thickness of 0.576 in.

This gives us the required $\frac{D}{t}$ ratio of 23.232. Approximate threaded and coupled weight of this casing would be 80 lb per foot.

Overall weight based on 80 lb per foot is 560,000 lb.

The foregoing typical casing strings represent only the preliminary work that needs to be done along this line. Strings of 6-in., 6⅝-in., 7⅝-in., 8⅝-in., and 10¾-in. also may be required for 20,000-ft casing programs in various oil-producing areas. The 9⅝-in. casing that is designed only to a depth of 13,000 ft might be used for a 15,000-ft string, and it would weigh in excess of 700,000 lb. A 7⅝-in. string run to 20,000 ft would weigh in excess of 750,000 lb. In order to design the remainder of a 20,000-ft drilling rig, a casing load of 20,000 ft of 40-lb pipe, viz., 400 tons, should be used.

Tubing

In designing 20,000-ft tubing strings, it would appear that using a single weight and grade of tubing would necessitate the use of a steel with a minimum yield strength of 145,000 psi, viz., some 35,000 psi higher strength than now being considered for the 20,000-ft casing strings. This is based on a safety factor in tension of 2, which is hardly considered sufficient to allow for fishing jobs, pulling of packers, etc. However, it is entirely possible that improvement in hydraulic pulling tools will tend to decrease the tension safety factor required for tubing. In regard to the bursting strength of tubing, it is believed that Barlow's formula should be used. As tapered tubing strings appear to be the answer here, this problem was not considered by this study group.

Drill Pipe

Drilling to 20,000 ft with security will require stronger drill pipe than

the present API grade "E," which has a minimum yield strength of 75,000 psi. One manufacturer is producing small quantities of drill pipe made of SAE 4340 steel, which has a minimum yield strength of 105,000 psi. By applying the same design factors to drill pipe as outlined previously herein for casing and tubing, a string of 4½-in. 20-lb drill pipe made of a 105,000-psi-minimum-yield-strength steel might be used for 20,000-ft. drilling. If the hole size is sufficient, a string of 5½-in. 25-lb drill pipe of 105,000-psi-minimum-yield-strength steel also might be utilized to total depth. Torsional strain is an important factor which should be considered; and, although 3½-in. 15½-lb drill pipe could be used to 20,000 ft, the chances of twistoff are much higher than when the larger-diameter drill pipe is used. Of course, the selection is limited to hole size, and tapered strings may prove to be the solution. At any rate, a drilling string of at least 20,000 ft of 25-lb pipe; i.e., 250 tons, should be used in designing for rig loads and power requirements for 20,000-ft drilling.

PRIME MOVERS AND HOISTS

Determining Factors for Hooks and Hoist Capacity

The maximum hook loads anticipated are 250 tons for drilling and 400 tons for running casing. The drilling load is the key factor, however. Casing loads can be taken care of by additional lines and slow speeds, whereas drilling loads involve fewer lines and greater speeds. We should assume derrick heights of 185 ft or more for 20,000-ft drilling operations. For casing jobs, the drum should be capable of spooling 1⅝-in. line for 12 lines down on the drum. The drum should be grooved, and should be wide enough to lift the kelly and to drill a joint of pipe and still be on the first layer of rope. This suggests a definite need for revision of hoist design. A drum 42 in. in diameter and 96 in. wide would have sufficient capacity for the wire rope to be on the second layer when an 8-line block, elevated to the top of a 135-ft stand of pipe, is used. For the design of the hoist, the minimum speed off bottom should be 100 ft per min. If we assume that heavier wire rope will give a life comparable to that of present size, we get 3.75 as the static safety factor on wire rope to be used for deep drilling. This safety factor is based on the formula:

$$\text{S.F.} = \frac{\text{(no. of block lines) (breaking load)}}{\text{hook load}}$$

It does not include sheave-efficiency losses. For drilling, 8 lines should be used at first, and the well should be finished with 10 lines. For the running of casing, 12 lines must be used. Based on a 250-ton hook load with a sheave-efficiency loss of 2 per cent, the drilling wire line load would be 74,500 lb for 8 lines, or 62,500 lb for 10 lines. Even when a 6 by 19 1⅝-in. wire line is used (which is the largest line available at present), the safety factors for these drilling loads are only 2.9 and 3.47, respectively. If a static safety factor of 3.75 is used, without allowing for sheave-efficiency losses, the hook capacities for 8, 10, and 12 lines of 6x19 hempcenter improved plow-steel wire rope are as follows:

Rope size (inches)	Strength (pounds)	8 Lines	10 Lines	12 Lines
1¼	129,200	278,000	346,000	416,000
1⅜	155,400	333,000	416,000	500,000
1½	184,000	390,000	487,000	585,000
1⅝	216,000	450,000	562,000	675,000

The drum diameters for the foregoing line sizes should be a minimum of 20 times the rope diameter, and, preferably, about 25 times the rope diameter.

It is felt that the wire rope manufacturers should develop a wire rope with more strength for a given diameter. It appears that the full effect of modern high-frequency heat treating and annealing, and of super alloys, has not been fully developed; that the oil industry in particular has had limitations in design, and that this has prevented the use of larger-diameter rope or additional lines in the block. Every effort of concentrated research for wire ropes with higher strength should be encouraged by the industry. It is generally believed that at present 6 by 19 Seale construction rope, with either hemp or wire center, offers the best promise for deep drilling. The chief function of the wire rope center is to prevent the crushing of the rope; it is not primarily for additional strength. The published strength of IWRC* rope should not be used for calculating safe loads, but the strength of hemp-center rope should be used for this purpose.

As a result of the foregoing comments, this letter was received:

"API. WIRE ROPE MANUFACTURERS' SUBCOMMITTEE
TRENTON 2, NEW JERSEY
"May 5, 1949

"MR. W. S. CRAKE
"MR. T. H. GIBBS

"We understand the following request for information from a local API study group on deep-drilling practice, under the co-chairmanship of Mr. W. S. Crake, of Shell Oil Company, Inc., Houston, and Mr. T. H. Gibbs, has been sent to a number of individual wire rope manufacturers:

"'Just what is the wire rope industry doing toward developing a rotary-drilling line with wires of a higher tensile strength? Has there been any consideration of using a wire other than carbon steel? What are the known possibilities of alloy wires incorporated into wire rope? What will the physical properties of alloy-steel wires be? Operators are cognizant of the fact that safety factors of 5 will probably not be able to be maintained. What would be minimum safety factors recommended using maximum hook load of 500 tons for casing operations? 250 to 300 tons maximum drill-pipe load with maximum fast line speeds of 4000 ft per minute? It should also be considered that present diameter of drums and sheaves will be revised upward in design of new rigs. Drums to be a maximum of 42 in., and fast sheave to approximate 6-ft diameters.'

"Since the API Wire Rope Manufacturers' Subcommittee has been giving active consideration to the problem of greater depths to which wells are currently being drilled (in which connection our committee has also asked other API committees to cooperate in the study by supplying needed information which we believe would be helpful in these studies), we are taking the liberty of replying to this questionnaire after having developed the consensus of our committee hearing upon the questions as outlined:

"1. *Development of Drilling Lines with Wires of Higher Strengths.*

"Higher-strength ropes than those currently used as rotary-drilling lines have been made, but such ropes have generally been confined to specialized service of a much different character where the strength-weight ratio is an important factor.

"It is to be noted that in this service the stress to be negotiated by the rope is principally of the nature of a straight pull as distinguished between the combination of axial loading and surface bearing pressures (resulting from drum and sheave action) in a rotary-drilling rig.

"There is danger that a considerable increase in the strength of wires, such as may be expedient in the case of rope subject to a straight pull only,

*IWRC = independent wire-rope core.

might result in loss of rope life in applications in which ropes are subjected to a more complex system of working, such as applies to a rotary-drilling rope. In the latter service it is of utmost importance to build a rope of wires that has a high degree of capacity to withstand the peening actions of bearing pressures and additional cold work imposed by the forces acting on the rope as a result of drilling service. The remarkable performance currently being realized from standard improved plow-steel rope supplied by American manufacturers, as compared with the reports of lesser service obtained from some foreign-made rope of somewhat higher strength (as one point of difference), appears to support our belief that our American practice of giving attention to other features than merely increasing rope strength, regardless of those other features, is the correct approach to the overall problem.

"2. *Alloy-Steel Wire.*

"During the past four or five decades a number of trials of alloy steel in rope wire have been made. The service results, however, have been disappointing. This probably is due to the fact that alloy steel does not have the same capacity to withstand the plastic cold flow in wire drawing as is possessed by carbon steel of a grade to produce wire of equivalent (or even higher) strength; i.e., the alloy steels appear to work-harden more rapidly. The stainless alloy steels are a good example of this; the justification of stainless-steel wire is found where the problem of corrosion is so much a factor that a sacrifice of the other characteristics possessed by plain carbon wire is in order. Moreover, alloys are usually added to steel principally to increase depth-hardening in heat treatment. This is important where the cross-section is relatively large; in the case of wire, however, the cross-sectional dimension is so small that this advantage becomes of very little relative importance and, in fact, is entirely unnecessary.

"3. *Safety Factors.*

"A safety factor of 5 is mentioned in this questionnaire. Our committee has suggested a safety factor of 4, with a minimum of 3.5 desired, in the belief that, if such could be provided by the design of drilling rigs, safer and more economical rope service would result from the use of improved plow-steel rotary-drilling lines than would be realized from the use of higher-strength ropes, even though the arithmetical safety factor appears to be higher.

"Larger drum and sheave diameters, together with larger rope diameters, will diminish the unit bearing pressure, and could reasonably be expected to enable the use of more moderate safety factors without serious reduction in rope life. We, at this point, feel justified in calling attention to the fact that, in engineering, safety factors can only serve as a guide in design, and that frequently it becomes expedient, from an overall standpoint, to not allow ourselves to be bound too closely by an arbitrary safety factor. We have in mind the flexibility observed by oil-country engineers in the design of casing strings for these same deep wells. If we make calculations on the basis of the catalogue strength of 6x19 improved plow-steel IWRC rope, and on the basis of a maximum line load on a 12-part line carrying a hook load of 300 tons of drill pipe, the safety factor for 1½-in. 6x19 IWRC rope would be in the order of 3.10; for a casing load of 500 tons, the same rope would have a safety factor in the order of 1.85, or 2.09 for a 14-part line. A 1⅝-in. 6 by 19 IWRC improved plow-steel rope, reeved as a 12-part line, would have a safety factor in the order of 3.60 for a 300-ton drill-pipe load, and of the order of 2.16 for a 500-ton casing load. Since the predominant working life of a rotary-drilling rope is involved with the drill-pipe load, we would be inclined to base calculations on that load rather than on the more infrequent load application encountered in running casing. These suggested calculations of safety factor are based on the following catalogue strength of IWRC wire rope, in pounds:

"Rope Diameter (Inches)	Strength
1¼	138,800
1⅜	167,000
1½	197,800
1⅝	230,000

"Very truly yours,

"API Wire Rope Manufacturers' Subcommittee

"A. J. Morgan, *Chairman*"

"AJM:ms

As mentioned previously, the study group feels that the foregoing safety factors, which are based on IWRC wire rope, should not be used for calculating safety loads. It remains to be seen whether sufficient rope life can be obtained when materially reduced safety factors are used in actual operations.

Brakes

At present the largest brake flange is 62 in. in diameter with a 36-in. diameter spool, or a ratio of 1.72. An 84-in. brake could, therefore, have a 48-in. barrel. The rig size already exceeds the mechanical brake capacity to carry the full load, and drawworks which are designed today require, as an absolute necessity, an assistance brake. Water cooling on the mechanical brake is satisfactory only between stands, and flame-hardening on the brake face is of insufficient assistance because the heat treatment is almost immediately removed by the heat from the braking action. Actually, the assistance brake is intended to be the primary brake in deep drilling; the mechanical brake is only supplemental. A modern hoist should *never* be operated at full speed when the assistance brake is out of order. Additional engineering should be applied to the problem of connecting the assistance brake to the drum shaft, and it is essential that the assistance brake be carefully engineered for a specific hoist to do a certain maximum job. In order to take the load off the driller, the handling of the hoisting weight should be taken off the brake lever. Remote controls and air hydraulic controls will help ease this load—which now consists of the man's weight times the lever arm. The brake should be self-energizing only to the extent that it will not "grab." An air brake is needed to protect the hoist—with the brake equipped so that a man will be able to "limp along" in the event the air should fail. The heavy-duty brake rims should remain water-cooled, however.

Drives

For speed-increaser drives, speeds of 6500 ft per min—with lower chain safety factors—are already in use. Chains lose efficiency at high speeds, but that does not hinder the braking because this loss provides a good means through which energy may be lost. In comparing chain drives to gear drives, it is felt that chain drives are more flexible. In order that gears may be used, and in order to avoid wearing out and replacement of these expensive parts, a complex and heavy gear case is necessary. Chain life has been, and still is being, improved. We feel that there is little justification or necessity for going to gear trains. Gears are satisfactory at high speed inside the drawworks, provided they have been engineered to suit the type of drive being used and provided they are still economical. Hydraulic and electric drives appeal to the user of gears because of their non-shock loading. Use of Morse-type chains should be considered as the nearest approach to gears. The maximum chain ratios should be no more than 4 to 1 at low speeds. A minimum of seven teeth should be in contact after the chain has reached the root position of the tooth on the sprocket. With regard to maximum chain speeds, it is felt that

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good current practice is satisfactory. For satisfactory service, the minimum pitch diameter should be used only on low gear. Higher pitch diameters on high-speed drives give longer sprocket life. The present practice of selecting the minimum number of teeth is considered satisfactory. Longer chain and sprocket life will be obtained by better lubrication. The chains should be totally-enclosed and flood-lubricated from a pump; this applies without exception on main drives.

Clutches

Jaw-and-spline subsidiary clutches should not be used for connecting loads except on shafts which actually have been stopped. All main clutches should be of the friction type. Interlocks should be provided so that no two clutches on the same shaft can be simultaneously engaged. The high clutch, which takes tremendous shock-loading from transmissions when loads are started up, should have much higher heat dissipation than the low clutch, and almost the same load capacity. For simplicity in operation, it is probably best to use identical clutches (high and low) unless hydraulic or electric drives are used where practically no slippage occurs when connecting. Main load-connecting clutches should be friction, hydraulic, or electric. Speed-change clutches preferably should be of the connecting friction type, and these can use high plate-loading and reduced heat-absorbing capacity because they would not be engaged under load. Consideration should be given to the use of electric eddy-current type of high-speed clutches because reduced maintenance would justify higher first cost. Connecting-type clutches—such as pump drives, engine-connecting clutches, and speed-change clutches—can use high plate pressures and reduced sizes because of the low order of slipping loads to be carried. Slipping load-connecting clutches must be heavy, and they should use low plate pressures and high heat-dissipation factors.

Number of Speed Steps

a. Mechanical. It is recommended that, for extra-heavy hoists, a minimum of eight speeds is required—and this in some form of geometrical ratio per step—in order to keep the area, which is bounded by each speed-chance step, constant under the constant-horsepower hyperbola.

b. Hydraulic. Because, over the full-load operating range, a 2-speed hoist fits hydraulic torque converters which have approximately a 2.2-to-1 efficient operating range, only 2 speeds are required to give efficient coverage of operating loads. Emergency loads are provided by stalled or inefficient operation of converters. Auxiliary heat-exchanger capacity may be required in order to cool converters on emergency pulls at low efficiency; and an alarm, which signals overheated converter fluid, should be available in front of the driller. Speed-torque curves attain about 92 per cent of the ideal constant-horsepower hyperbola.

c. Electrical. If the 200 per cent overload capacity of modern motors and generators is used for the hoisting-duty cycle, two speeds may be used for electric drive. If the motor horsepowers are doubled once again, and if, in addition, generator capacity is doubled so as to obtain a quadruple current rating, a single-speed electric hoist can be made. There seems to be no economic justification for the increased weight and size of such equipment; however, mechanical-efficiency increases would be more than offset by electrical losses in oversize generators and motors.

By use of the isochronous governor, 100 per cent of ideal constant-horsepower hyperbola can be obtained. Conventional Ward-Leonard controls can approximate the ideal curve, and they will give about 92 per cent of its power. If a conventional single-motor drive is used, a 4-speed geometrically-spaced hoist is needed so as to keep as low as possible the area under the steps under the curve.

Overall Speed Ratios

a. Mechanical. Because of the fact that, normally, engines cannot take full loads at less than 50 per cent speed without danger of stalling, an overall ratio from low to high should range between 12 to 1 and 14 to 1 in order to permit sensitive handling of heavy loads at low speeds.

b. Hydraulic. The 2 speeds can be kept at about a 2-to-1 ratio, thus giving an overall efficiency ratio of approximately 4 to 2 to 1.

c. Electrical. A 2-to-1 hoist ratio can be used with double-horsepower motor drive. A 4-speed hoist with a single motor can use a 4-to-1 overall range.

d. Steam. Current designs have an overall ratio approximately between 4.6 to 1 and 5 to 1, inasmuch as there is little torque conversion on a steam engine except the droop of the speed-torque curve.

Drive Efficiencies

a. When the chain on high-speed drives is loaded heavily, a 5- to 7-per-cent loss per chain may be expected. The best assumption seems to be about 93 per cent efficiency, at full speed and full load, per set of 2 shafts and 1 chain drive.

b. Gears suitable for oil-field use would probably run 96 per cent efficient per set of gears and 2 shafts.

c. Block-line losses run from 1½ to 2 per cent per sheave, including bearings; 1½ per cent should be the figure for sheaves of good proportion which have roller bearings; 8 lines strung up would give about 10.3 per cent loss; 10 lines, 13 per cent loss; and 12 lines, 15.5 per cent loss.

Transmission

a. Mechanical. Assuming 7 per cent full-load loss per chain and shaft, 4-engine drive, and 5 chains in use to the average engine, about 69 per cent of the power reaches the cable; and, on an 8-line hookup, about 62 per cent reaches the hook.

b. Hydraulic (2-speed hoist) 3-engine drive. Assuming 80 per cent mean efficiency of torque converters, 7 per cent loss per chain, and 4 chains to the average engine, 60 per cent of the power reaches the cable; and, on an 8-line hookup, 54 per cent reaches the hook. Part of this is recovered by the possibility of running engines at higher revolutions per minute with hydraulic drive.

c. Electrical (2-speed hoist). Assuming 94 per cent generator and 94 per cent motor efficiency, 2 per cent cable losses, and one chain in use at 7 per cent loss, 80 per cent reaches the cable; and, on an 8-line hookup, about 71 per cent reaches the hook.

d. Steam. Assuming 7 per cent loss per chain, 90 per cent mechanical efficiency of engine, and 3 chains in operation, 72 per cent reaches the cable on an 8-line hookup and about 65 per cent reaches the hook.

Catshafts and Catheads

As currently constituted, the best catheads perform satisfactorily. The need of eliminating catheads for pipe handling is still a pressing problem, however. Development of proper remote control of catheads should be pursued intensively. Means of applying fixed torques to pipe makeup by controlled pneumatic or hydraulic pressures on operating cylinders are now available, and should be continued.

Coring Reels

Probably 300 hp is ample for coring reels at any depth. In the case of an electric rig, the same electric motor which drives the rotary could satisfactorily handle the cathead shaft and the coring reel in one unit. It is recommended that attention be given to the design of proper rotary-table cor-

ing-reel catshaft units that are remotely operated from the driller's position, which can be placed at any desired point.

Rotary Drives

It is probable that 300 hp is ample for the rotary drives. Independent drives are recommended, and electric drives are ideal because the sensitive torque control of an electric motor is much simpler than with a torque converter. A special generator to drive the rotary or rotary-catshaft coring-reel unit is probably the most flexible drive, and has the lowest possible maintenance cost. Bringing chain drives up to the floor from the ground level is easy neither for rigging up nor for maintenance. The position of the drawworks can be made to suit the hoist only if there is no mechanical connection to the rotary table.

Emergency Hoisting

Some form of emergency hoisting unit is recommended. The most practical solution appears to be to provide about one-tenth to one-sixth of the horsepower of the main prime movers as emergency power, and to connect this to the main hoist through a torque converter. With modern hoists, it is almost inconceivable that a main shaft would break down, and it is believed that full-size, or even half-size, emergency hoisting equipment can never be economically justified. A special one-sixth-size deadline hoist might be justified to eliminate the possibility of any breakdown of a main clutch and to facilitate wire rope handling.

Prime Movers and Transmission

As between gasoline, butane, gas, and diesel engines, the trend on heavy rigs continues toward the diesel engine because of its economical operating costs, especially on wildcat wells. The dual-fuel gas-diesel engine has been cited as the most desirable type for oil-country use, although field runs so far have not demonstrated that satisfactory oil-field units are yet available. Natural gases with varying Btu content and entrained liquids do not result in a satisfactory fuel. It was pointed out that, on idle running, diesel fuel of 15 to 20 per cent of total requirements usually means only a 40 to 50 per cent total saving in the fuel bill because of low average load factors on heavy rigs. So far the variable-loading and speed conditions on rigs are not conducive to good dual-fuel operation, although 3-per-cent injection fuel is satisfactory on heavy constant-speed constant-load engines. The next best type of engine, i.e., more practical and longer established, is the convertible engine. This may be attained by changing cylinder heads and pumps, or, preferably, by changing head parts without requiring opening up of engines to change fuel types. This general type would be converted to full-gas spark-plug engines in a field where gas fuel was more economical than diesel fuel.

Horsepower for Hoisting

For exploitation drilling, there is no reason for departing from the conventional figure of "100 ft per min off bottom"; and this involves a 250-ton maximum hook load—which is about 1600 hp, or, at the efficiencies previously cited, an engine-shaft horsepower of about 2800, intermittent rating. This figure may be dropped to 75 per cent of this amount for wildcat rigs, i.e., an engine horsepower of 2400; and this could be reduced if lighter drill-pipe strings were contemplated. When engines are selected, careful allowances should be made for altitude and temperature—especially in the case of supercharged engines using turbo blowers that are sensitive to compression-ratio changes and radiation of the heat of compression. It is generally agreed that, on ultra-heavy rigs, four prime movers is the most desirable number. In case of one unit failing, 75 per cent drilling capacity would be available; whereas 66 per cent capacity for a 3-unit assembly with one outage would impair drilling operations considerably. More engine units involve excessively complicated transmissions and higher power losses.

Slush-Pump Drives

A twin-pump drive is considered most desirable, i.e., one drive from the rear of the transmission, and one from the No. 2 engine shaft, counting from the drawworks. Both drives would supply similar sized large pumps, and this would involve 2 engines with a shaft horsepower of about 625 (continuous rating) into one pump—making about an 1100 hp input available for each pump. Operation would have to be very carefully watched to prevent pump overloads. For the driving of slush pumps, the use of the converter, including a hydraulic coupling, is recommended as giving only about 3.1-to-1 multiplication ratio against 5-to-1 on the straight torque converter. This would prevent dangerous overloading of pumps and higher overall efficiencies at less than full-throttle operation. Hydraulic couplings with a constant torque limit and variable horsepower are advantageous chiefly for the prevention of shock loading from engines to rig, or vice versa, with the further possibility of a reduction in maintenance. For the capital expenditure involved, the torque converter (which yields constant horsepower) and the variable torque are much more desirable.

Loads, Speeds, Etc.

The size of the previously described individual engine, or of the twin engine, would be from 600 hp to 700 hp, intermittent rating. If 3 engines were used, an intermittent rating of 800 hp to 930 hp would be required. The torque-converter drive is desirable, especially because it permits the use of higher-speed engines on heavy rigs. The 1800-rpm torque converter is the most desirable because it is light and economical, and because the lower-speed converter units rapidly become excessively bulky and costly. The recent appearance of a V-12 400-hp 1800-rpm torque-converter engine unit presents interesting possibilities for the use of 4 "twin" units of 400 hp, or 3200 hp in all; or, alternatively, 3 "twin" 400-hp units and one "single" 400-hp unit, so that 2800 hp could be used. The single "400-hp" would be the No. 1 engine, and this could be used for normal rotary-table drive.

The average load factor over the drilling of a well is believed to be about 20 to 25 per cent. In order to anticipate engine overhauls and the best use of the engines, both engine-running hour indicators and individual fuel meters are desirable. Either permanent thermocouples in each cylinder exhaust, with multi-point pyrometer connections or a portable means of checking engine-exhaust temperatures by portable instruments, should be available to the engine man. The use of hydraulic torque converters or electric drives permits the economical use of engines of higher speed than direct mechanical drives. Whether the advantages of portability and low first cost will balance the higher maintenance costs has not as yet been determined. It appears that the use of higher-speed engines will require a somewhat different approach to the maintenance problem because more careful and frequent attention to engine checking will be required. This is not a major problem, but it does require careful and intelligent development. On gas-gasoline and butane engines, load balancing is handled merely by making the manifold vacuum of one engine control the throttle of the others. On diesel mechanical rigs, load balancing can be obtained only after careful adjustment of throttle settings against pyrometer exhaust temperatures, and this only works with moderate success. In purchasing engines, proper attention to engine-

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governor characteristics is necessary so that governors with low regulation (probably 3 per cent) and proper speed-droop characteristics will be obtained. This will prevent engines from "pulling down" excessively in "revolutions per minute," to a point where they might never give full horsepower—thus resulting in the waste of money for horsepower not deliverable. On hydraulic rigs, or on properly equipped electric rigs, the hydraulic or electric circuit tends to balance engine loads if close approximate settings are made. The isochronous electric governor balances loads perfectly. This easily may mean 5 per cent more power to the hook that otherwise might be wasted when engines "fight" each other.

Engine Cooling

On large rigs, it is believed highly desirable to go to the hot engine, or operation at about 212 F. "Vapor-phase" cooling or variable-pitch fans, i.e., dynamic or eddy-current-type fan drives, with closed radiators operating under pressure, may be employed. In order to make large rigs independent of wind direction, and for the purpose of keeping cooling systems to the smallest size possible, the independent cooling unit with horizontal updraft radiators is recommended—using a central system of cooling fluid which feeds to all of the engines. In this way radiators are not exposed to engine vibration; natural-draft direction is employed; and a minimum of horsepower is robbed from engines for cooling purposes. Twin electric drives of such units from two separate engines is recommended, or a drive from alternating-current auxiliary units may be used.

Auxiliaries

The use of duplicate standard high-speed alternating-current packaged power units for driving auxiliaries is recommended. The use of standard alternating-current motors and switch gear for compressors, fans, mud-stirring devices, water pumps, etc., is generally more economical than the purchase of similar direct-current motors and equipment for heavy rigs.

Pumps, Bits, and Blowout Preventers

Pumps

The mud pump, which serves to maintain circulation through the drill pipe to keep the bit clean by nozzle velocity and to remove the cuttings through the annular space, has always been the largest consumer of energy in drilling a well. This horsepower requirement, transformed into mud volume and pressure, increases almost directly as the depth for a given size drill pipe in a given size hole. On power rigs, circulation problems are numerous in drilling even below 12,000 ft; thus 20,000-ft drilling offers a definite challenge to the rig pumps.

Inasmuch as the primary function of the drilling mud is to remove the cuttings from the hole, the pump size is largely dependent on the size of the cuttings and on the necessary rate of the return velocity. Simple calculations show that average bit-cuttings sizes may be quite small for fairly rapid drilling, and that they are extremely small for slow drilling; therefore, because the shale fragments that can be seen on the shaker are larger than calculated cuttings sizes, they are most likely to come from those places in the walls of the hole that are shown by caliper surveys to have a tendency, with elapse of time, to increase in diameter. This suggests that the fragments, as they are broken from the walls, may be larger than an ordinary mud-circulating rate could carry; it is only when the fragments are rebroken that they become of such a size that the mud can carry them out of the hole. It is also felt that bits often grind and regrind the newly dug cuttings before the mud has removed them from the bottom of the hole. The so-called "jet bit" has been developed to keep the bit clean.

With such variables undeterminable, it appears that the selection of mud-circulating rates will have to continue on an arbitrary basis, such as "200 ft per min upward velocity in annular space." This, of course, refers to gage-sized hole—it being understood that there will be varying diameters for over-gage hole depending on various factors.

Table 1 presents an interesting study in the relationship between horsepower, drill-pipe size, and hole size for 200 ft per min upward velocity.

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governor characteristics is necessary so that governors with low regulation (probably 3 per cent) and proper speed-droop characteristics will be obtained. This will prevent engines from "pulling down" excessively in "revolutions per minute," to a point where they might never give full horsepower—thus resulting in the waste of money for horsepower not deliverable. On hydraulic rigs, or on properly equipped electric rigs, the hydraulic or electric circuit tends to balance engine loads if close approximate settings are made. The isochronous electric governor balances loads perfectly. This easily may mean 5 per cent more power to the hook that otherwise might be wasted when engines "fight" each other.

Engine Cooling

On large rigs, it is believed highly desirable to go to the hot engine, or operation at about 212 F. "Vapor-phase" cooling or variable-pitch fans, i.e., dynamic or eddy-current-type fan drives, with closed radiators operating under pressure, may be employed. In order to make large rigs independent of wind direction, and for the purpose of keeping cooling systems to the smallest size possible, the independent cooling unit with horizontal updraft radiators is recommended—using a central system of cooling fluid which feeds to all of the engines. In this way radiators are not exposed to engine vibration; natural-draft direction is employed; and a minimum of horsepower is robbed from engines for cooling purposes. Twin electric drives of such units from two separate engines is recommended, or a drive from alternating-current auxiliary units may be used.

Auxiliaries

The use of duplicate standard high-speed alternating-current packaged power units for driving auxiliaries is recommended. The use of standard alternating-current motors and switch gear for compressors, fans, mud-stirring devices, water pumps, etc., is generally more economical than the purchase of similar direct-current motors and equipment for heavy rigs.

Pumps, Bits, and Blowout Preventers

Pumps

The mud pump, which serves to maintain circulation through the drill pipe to keep the bit clean by nozzle velocity and to remove the cuttings through the annular space, has always been the largest consumer of energy in drilling a well. This horsepower requirement, transformed into mud volume and pressure, increases almost directly as the depth for a given size drill pipe in a given size hole. On power rigs, circulation problems are numerous in drilling even below 12,000 ft; thus 20,000-ft drilling offers a definite challenge to the rig pumps.

Inasmuch as the primary function of the drilling mud is to remove the cuttings from the hole, the pump size is largely dependent on the size of the cuttings and on the necessary rate of the return velocity. Simple calculations show that average bit-cuttings sizes may be quite small for fairly rapid drilling, and that they are extremely small for slow drilling; therefore, because the shale fragments that can be seen on the shaker are larger than calculated cuttings sizes, they are most likely to come from those places in the walls of the hole that are shown by caliper surveys to have a tendency, with elapse of time, to increase in diameter. This suggests that the fragments, as they are broken from the walls, may be larger than an ordinary mud-circulating rate could carry; it is only when the fragments are rebroken that they become of such a size that the mud can carry them out of the hole. It is also felt that bits often grind and regrind the newly dug cuttings before the mud has removed them from the bottom of the hole. The so-called "jet bit" has been developed to keep the bit clean.

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it is planning some experiments in which vertical cylinders of concrete "formation," approximately 10 in. in diameter, will be subjected to very high lateral and bottom pressures at intermittent intervals, and that at other intervals they will be unstressed, while a hole approximately 4 in. in diameter will be drilled down the middle. It is hoped this will result in information concerning the effects of the natural surrounding pressures upon the "drillability" of a given type of rock at the bottom of a deep well, so that a comparison may be made with the apparently easier "drillability" of cores which currently are brought out of the well and then tested in the laboratory. It would be desirable to obtain some larger and more representative cores of such formations, or some specimens of surface outcrops. One producer describes the unusually heavy characteristics of the cuttings from a deep well in Pennsylvania, wherein the mud properties had to be built up so that the mud could effectively carry the cuttings.

Considerable controversy exists concerning the effects of drilling-fluid properties on rates of penetration. Field reports — especially those from West Texas, where considerable drilling is done with "water" without the addition of mud materials—indicate that drilling rates are reduced almost one-half when "mudding up" is required to obtain better delivery of cutting samples, particularly when special "low water-loss" mud is used to minimize sloughing of certain shale beds and to avoid a tight hole which might result from mud-filter cake on permeable zones. Laboratory work does not appear to correlate consistently with field reports concerning the extent of the adverse effects of drilling muds upon drilling rates. However, laboratory tests do show that an increase in drilling rates of as much as 15 per cent results when air is used, instead of water, to clean the bit and the surface of the rock which is being cut. It also appears that the cutting fragments are larger when air is used. This, of course, is in line with normal expectation, i.e., that larger cuttings accompany faster drilling.

There is some question as to whether the energy of jets from bit nozzles are dampened in a shorter distance in heavy mud than in water. No definite answer seems available, but it is felt that the heavier mud jets would have more energy, at the same velocity, because of greater mass. There seems to be considerable opinion that the effect of muds upon cutting rates is closely related to an adhesive effect which tends to make the newly crushed fine cuttings adhere to the bottom, and to one another; and this "cushions" the indentation pressure of the bit edges. It is also possible that the lubricating effect of the satisfactory mud prevents the bit edge from developing as much friction in contact with formation, just as a lubricant prevents wear of gear surfaces — which, although they have been designed to avoid abrasion, do wear badly with non-lubricating fluid. Another possibility is that the differential pressure between the mud and a "normal" pressure in a permeable formation makes the mud "hold a cutting against the formation;" this might be enhanced by the viscosity, and by the coating properties of a mud, in contrast to water which would work under the cutting more readily but would not maintain a differential pressure over it.

One bit manufacturer discussed the effectiveness of the 'combination bit," which has both blades and rotating cutters. Formations such as shales can be dug more rapidly by sharp blades than by rotating cutters; and, although they tend to dull the blades very rapidly, they do not dull the cutter teeth. Such formations frequently are encountered in certain parts of the Gulf Coast.

In general, it appears that present bits are suited to deeper drilling. Suggestions for further investigation and study are:

1. That mud engineers try to develop muds which do not retard drilling but which at the same time will serve other purposes effectively.
2. That formation specimens be obtained so that laboratory drilling will correlate with deep drilling.

Blowout Preventers

In order that the requirements for blowout preventers may be predicted, formation pressures must be estimated. It is conceded that the formation pressures could not be any higher than the equivalent of the "overburden pressure;" otherwise the formation would be fractured and the overburden would be lifted. The general consensus is that the overburden is equal to approximately 1 lb per foot of depth. The customary references to overburden pressure seemed to be based on a curve, published about 10 years ago, which showed a pressure of about 10,000 psi at about 10,000 ft, but which had a slightly more gradual gradient at lesser depths and a steeper gradient at greater depths. It is believed that this was estimated on different porosities, and that deeper formations may have less porosity and higher unit weight. However, it is estimated that, at 15,000 ft, the compressibility might involve only a 1 per cent reduction in volume (or 1 per cent increase in density) as compared to what might be observed with a core sample brought to the surface.

Present blowout-preventer practice for wells 10,000 ft to 15,000 ft deep is to use 10,000-lb test equipment; whereas casinghead practice frequently calls for 15,000-lb test equipment. It is apparently felt that the blowout preventers will almost always have the benefit of a parital mud column to restrain high bottom-hole pressures, whereas the casinghead on a gas well receives a higher proportion of the bottom-hole pressure. One company has designed and built one 10-in. blowout preventer for a 15,000-lb test. Standard flange design appears to have resulted in flanges somewhat thicker than necessary for reasonable stress.

In addition to the comparatively simple problems of closing blowout preventers on stationary pipe, deeper drilling in higher-pressure zones may involve problems of holding pressure at the surface during drilling. Reference was made to assemblies for "back-pressure" drilling done by a major company. This company found it desirable to operate with a mud column having a slightly smaller pressure than the formation pressure; but this was supplemented in part by upward flow friction and in part by surface pressure during the drilling operation. When mud was not being circulated, counterbalance was effected by a somewhat larger surface pressure. Such an operation would require a packoff for the rotating equipment, as well as control devices on the outflow of mud and cuttings. One device for this might be a hydraulic motor which would consume the outflowing mud pressure, and this motor might also deliver power to a mud pump. Another method would be to pass the mud through a pressure settling tank, so that the cuttings would be dropped out; then the mud could flow out through the chokes without frequent clogging. These methods were tried by one major operator, but improvements were found necessary.

Other installations have involved elaborate choke manifolding, whereby a transfer can be effected from one choke to another if one of them should become clogged with cuttings. However, the use of back pressures at the surface appears limited, for the reason that there is but slight difference between the bottom-hole pressure conditions maintained by a column of mud of a certain weight and those which are maintained by a lighter

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mud plus surface pressure—assuming, of course, that in both instances there is the same bottom-hole pressure based on the required formation-fluid pressure, and limited by the formation-breakdown pressure which may not be exceeded.

It is generally believed that the present preventers, or combinations thereof, will handle ordinary drilling to 20,000 ft. Abnormal conditions might arise, however, in which the present size of equipment would not be adequate.

TECHNIQUES

Selection of Hole Sizes

It is generally conceded that the control factor in the selection of hole size is entirely dependent upon the size of the drill pipe and casing which can be used to drill to 20,000 ft. Although casing practice varies with locality, a typical example of setting casing might be as follows:

Casing and Bit Program

Bit size (inches)	Casing size (inches)	Setting depth (feet)
26	20	1,000
17½	13⅝	7,000
12	9⅝	15,000
8¾	5½ or 7	20,000

As mentioned previously under "pumps," large-size drill pipe should be used in order that the hydraulic horsepower requirement will not become prohibitive when these large-size holes are cut. Drill pipe as large as 6⅝ in. in diameter may prove desirable. Several operators along the Gulf Coast believe that an additional casing size will be required as a protective string so as to permit the drilling of reasonably sized holes to below 14,000 ft. Ideal operations might require 5 casing strings set to depths of approximately 2000 ft, 7000 ft, 12,000 ft, 16,000 ft, and 20,000 ft.

Mud Control

It is agreed that circulating capacity should be sufficient to develop a minimum return velocity of 100 ft per min, and that velocity of 200 ft per min is desirable. Return velocities should be held within the range of viscous flow, inasmuch as the carrying properties of mud are dependent upon correct velocities more than on any other single adjustable property. Present practices and techniques are sufficient for the control of viscosities and gelation properties for deep drilling, and it will be necessary to modify only slightly the present techniques and equipment to meet the problems of deeper drilling. It is anticipated that improvements in methods and materials for controlling filtration properties will be made, provided past experience may be used as a guide for anticipated development. Because of the higher temperatures that will be encountered, it will be necessary to utilize mud-cooling equipment to reduce chemical costs and to improve physical properties. Temperature will affect mud properties in such a way as to alter materially electrical logging results; much thought should be given to the control or alleviation of this condition. It appears that no special type of mud will be required because of increased depth. However, it will be necessary properly to choose muds which already have been developed, and to apply them carefully. Abnormal pressures in formations probably will increase as average depth of drilling increases. It has been established by current drilling data that formation pressure will approximate a maximum of 0.8 lb per foot of depth. With few exceptions, it is not expected that this factor will change much at greater depths. Materials for mud weights and densities adequate to control both normal and anticipated formation pressures are currently in use, and are now available. However, it may be necessary to develop some type of lost-return material or mud to seal fissures which may become increasingly troublesome with deeper drilling.

As mentioned previously in the discussion on bits, there are some localities, such as West Texas, where the use of drilling mud retards penetration as much as 50 per cent, compared with drilling rates in "water." Data have been accumulated which indicate that changes in bit design will affect materially the drilling rate obtained with mud.

Methods for Determining Formations Encountered

Two major manufacturers of conventional and wireline coring equipment have expressed the opinion that no obstacles have been encountered to date that will minimize the success of this equipment. The present materials and design of both wire-line and conventional equipment are capable of withstanding the pressures and temperatures anticipated at 20,000 ft. However, an increase in depth will result in a decrease in core size when wire-line equipment is used, whereas conventional or diamond coring should maintain normal size cores.

With regard to side-wall sampling of formations, one manufacturer, who utilizes a punch-type barrel for obtaining samples, states that he anticipates difficulty with the equipment at deeper zones because of the excessive hardness of the formations. One manufacturer, who uses a percussion-type sample gun, is also of the belief that difficulty will be met in obtaining samples because the harder formations and higher temperatures will affect the power loads. Also, the small hole size will limit side-wall coring success, because 5½-in. is the minimum hole through which samples of that type can be obtained. One manufacturer, who uses a small core bit to drill into the side wall, explains that hard formations will cause no difficulty with his sampling equipment; however, an 8½-in. hole is the smallest through which he can now operate.

When drill cuttings are used to determine the formation encountered, there is considerable uncertainty as to the accuracy of the cuttings screened from the mud system. One supplier of mud-weighting material believes that the cuttings are accurate only within 50 ft or 100 ft, and that the depth of the parent formation may be established by correlation of drilling rate, return velocity, and estimated slippage of solids in the mud. It is the opinion of a number of operators that solids may slough from the hole wall at points distant from the bottom — thereby creating a false impression. With increases in depth to 20,000 ft, inaccuracy with the use of drill cuttings probably will increase considerably over current experience.

From a mechanical standpoint, electrical logging to depths of 20,000 ft should not prove difficult. However, high temperatures affect the resistivity of muds so strongly that much study should be given to the elimination of this difficulty. There is a possibility that FM logging may proceed successfully at temperatures up to 350 F, and it is now possible to operate successfully with induction logging at temperatures as high as 320 F.

Cementing Practices

Fig. 3 shows a series of laboratory tests that were made on various cements. This indicates that the present types of cement are not adequate for 20,000-ft completions. The tests show that an average of 1 hour and 11 min in pumpability time may be expected from current types of slow-setting ce-

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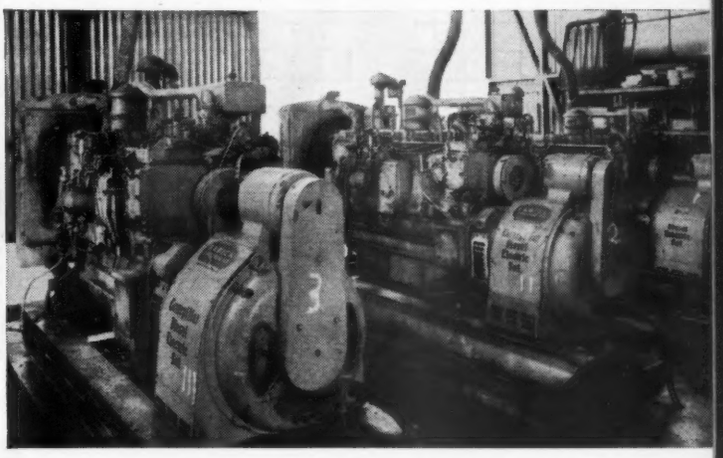

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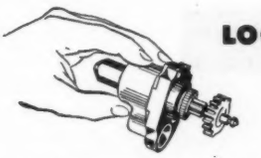

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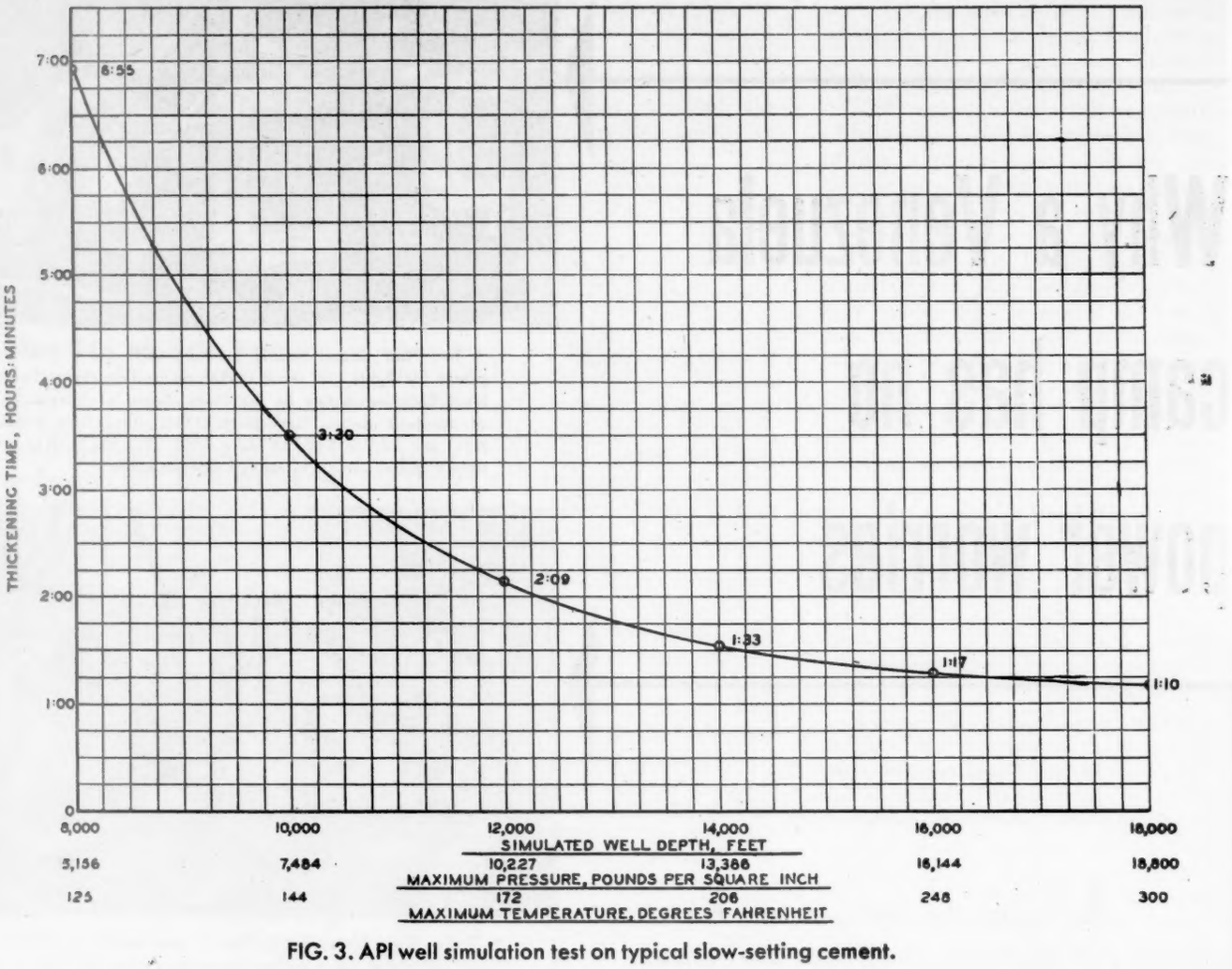

FIG. 3. API well simulation test on typical slow-setting cement.

ments in an ordinary temperature-gradient well. It is also felt that high pressures seriously accelerate the setting time of cements. At present no one type or brand of cement classified as "slow-set" offers any material advantage in setting time. One major cement manufacturer states that efforts are being made to develop admixtures to solve this deficiency. Although laboratory results indicate that present cements are inadequate for 20,000-ft depths, the oil industry has already witnessed the drilling and cementing of one well at close to this depth. Results obtained on this well prove that it is possible to secure a casing string at such a depth with the cements now available; however, it would be unwise to lessen attempts to develop a safer and more suitable product.

One special technique in cementing practices which may prove worthwhile in deep drilling is acidization immediately ahead of cement jobs. Running a balanced volume of wash acid and mud acid — followed by a small volume of water that is then squeezed out ahead of the cement—has resulted in improvement on a number of squeeze jobs. This procedure has reduced the number of squeeze jobs; has increased the effectiveness of such jobs; and appears to have increased bonding. It is noted that, in conjunction with the use of acids, the technique of slowing down the delivery rate during squeeze jobs appears to aid in obtaining a good shutoff. The theory behind this is that the acid removes the mud cake and offers faster dehydration possibilities. The slowing down of the delivery rate gives the cement an opportunity to thicken because of the water loss, and thus effects a seal. Acid volumes run on prime cement jobs do not appear to have any advantage.

Low water-loss cements are desirable when scratchers are used on test wells, or when it is anticipated that the fill-up will be high. Recent results in deep wells would indicate the use of scratchers, and centralizers may be continued in 20,000-ft wells without additional hazard or change in methods. It appears that floating equipment will have to be made stronger; it will have to stand much larger volumes of circulation. The ability to withstand abrasion must be increased. Not only will displacement volumes increase with depth, but the desirability of periodic circulation during the running of pipe is increasing. Periodic circulation is becoming common practice when small holes are made. At the present time plastics do not seem ready for use in extremely deep wells.

Well-Depth Measurements

Well-depth measurement has become increasingly important because of the difficulties encountered in the successful completion of oil wells wherein relatively thin oil-producing sections are encountered in intimate contact with gas and water sands, especially at increasingly greater depths. Current practice is to use drill pipe as a medium for determining depth, and it is felt that one of the principal sources of inaccuracy in this type of measurement is human error. These errors may be minimized by having the measurements checked by other personnel. The stretch in drill pipe caused by its own weight also becomes

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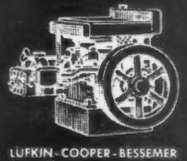
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increasingly serious in deep wells, and it is considered desirable to measure pipe in tension while it is hanging in the elevators. At depths of 20,000 ft the formations, if economical to produce, should be thick enough to tolerate an error of 2 ft or 3 ft. As the producing depths increase, correct perforating probably will depend more and more on correlated electrical logging methods, such as radioactive markers, gamma ray, neutron logs, casing-collar counters, and others.

Completion Practices

One operator states that the maximum temperature to be expected in 20,000-ft wells will approximate 400 F. If this is true, the present type of powders used in gun perforating probably can be used; however, speed of operation will be critical. Several powders have an upper limit of 280 F. The powder used in some jet shots seems to be good for 5 hours at 350 F. Obtaining of accurate high-temperature readings is doubtful when thermometers are subjected to high pressures. For the best results, the mud should be properly conditioned, both for the sake of measurements and gun-perforating efficiency. The strength of the perforating cable is now adequate for 20,000-ft operations; however, the clearances of the guns will become closer and more critical. One service company feels that 350 F is the maximum temperature for safe operation. Inasmuch as the success of the powder is determined by the time and the temperature, proper powder selection is essential; furthermore, the upper temperature limits of the equipment as well as the powder should be carefully checked before an ultra-deep drilling job is attempted. Another service company states that the collar-check technique permits of high-speed operations; getting into the zone is affected quickly, and the time necessary for positive location of the zone is minimized. At present collar-checking equipment is not available for flush-joint pipe.

It is anticipated that consolidation and screening of sands will not be necessary at depths between 15,000 ft and 20,000 ft because of hard, consolidated formations. At present plastics are limited in use at higher temperatures, although one company has successfully completed a plastic job at 251 F, and it believes that a higher-temperature plastic can be developed.

It is the general opinion of the major wellhead equipment manufacturers that surface equipment offers no real problem; furthermore, liners should present no problem peculiar to depth. Present design of packers is definitely not adequate for depths below 13,000 ft.

Acknowledgment

This compilation has been made possible because of the efforts of T. J. Fuson, of Humble Oil and Refining Company, and C. W. Alcorn, of Falcon Seaboard Drilling Company, who were chairmen of the Houston Chapter of the API Division of Production during 1948 and 1949, respectively, as well as by the efforts of the following 8 study group co-chairmen who presided over the meetings:

W. S. Crake, Shell Oil Company; T. H. Gibbs, Bethlehem Supply Company; R. A. Bobo, Phillips Petroleum; S. H. Reynolds, National Tube; T. W. Keating, Stanolind Oil and Gas; R. C. Chenoweth, Wilson Supply; G. E. Cannon, Humble Oil and Refining; H. F. Hopkins, Halliburton Oil Well Cementing Company.

The author wishes to extend his sincere thanks to these co-chairmen for having developed this information, and to the members of the study group for their many contributions and comments. Appreciation is also extended to the API Houston Chapter for permission to present this paper.

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Cures for Corrosion in Gas Condensate Wells*

W. H. STEWART†

THE search for gas and petroleum in the past few years has been driven to deeper and deeper horizons. Where gas wells are completed at great depths, extreme pressures are frequently encountered, making necessary the installation of expensive heavy duty equipment and piping.

Early in 1944 it became evident that some form of vicious corrosion was attacking both tubing and christmas tree fittings on some high pressure gas wells. The problem became rather general among producers and as a consequence a committee was formed within the Natural Gasoline Association of America to study and, if possible, arrive at means of mitigation of this expensive burden.

This committee met and organized in May of 1944 with Thomas S. Bacon of the Lone Star Gas Company as its chairman. Various forms of possible mitigation were studied. Since the problem was so complicated, the committee decided that an adequately financed program of research would be necessary. With the requested financial backing from the operators the committee launched into a study of this particular type of corrosion.

In May of 1944, Battelle Memorial Institute was engaged to study certain phases of the problem, particularly in laboratory studies in pressure vessels of various alloys in corrosive media. Carbon dioxide was at first thought to be mainly responsible for the acid attack on metal surfaces encountered. Battelle, likewise, constructed apparatus with which to examine the possibility of electrical accumulation and flow at certain points in the system being a factor. Numerous wellhead fittings from corrosive wells were submitted for examination and analysis by the institute to ascertain, if possible, how various metals and alloys reacted to this form of corrosion.

The United States Bureau of Mines likewise was brought into the picture late in 1944 and made a very exhaustive study of various alloys and steels in known corrosive solutions. At the same time, various chemical inhibitors were being investigated both at the Bartlesville Laboratory and in produced wells in several fields. Extensive field testing, particularly with sodium chromate, was carried out and reported most thoroughly by the Bureau. This work by the Bureau was done under the direction of Kenneth Eilerts.

By this time it had been definitely established that the waters, produced with the hydro-carbon condensate, contained an appreciable amount of organic acids which was found to modify the action of the carbon dioxide.

In January of 1945, the NGAA committee agreed with a similar committee of the National Association of Corrosion Engineers to apportion certain phases of the study to the NACE committee, so as to avoid duplication of efforts. As a result of this agreement the NACE committee undertook the study of alloys under actual field conditions.

These alloys (32 in all) were tested in high pressure chambers mounted directly in the flow stream with 4 coupons to represent each alloy and control at 4 separate locations in the container. This was necessary, as a definite drop in the corrosion rate from upstream to downstream end had been established in tests on the container for just this reason.

In April of 1945, a Fellowship was established at the University of Texas under the direction of H. L. Lochte to study water analysis with specific identification of the organic acids as present in these waters.

In order to broaden the investigation to include a study of physical chemistry in relation to inhibitors, a second Fellowship was established at the University under the direction of Norman Hackerman. William A. Cunningham's routine water analysis studies were later merged with investigations being made under Hackerman's studies.

In March of 1946 a field co-ordinator was considered essential to oversee coupon installation, sample gathering and various phases between the laboratory and field. D. A. Shock of the University was employed to fill this position. The installation of corrosion test coupons, gathering and storing of condensate, water samples and other similar duties fell under Shock's work. This post was discontinued in mid 1949 upon Shock's resignation.

Inhibitors

Extensive research on inhibitors, both in the laboratories and under actual field installations, has been carried on. Individual operators have been very co-operative in reporting results both good and bad with these treatments.

The Bureau of Mines exhaustively investigated the efficacy of sodium

TABLE 1. Survey on condensate wells.

Company	Total number wells	Number corrosive wells	Number w/alloy tubing	Number w/baked on coating	Number of wells using inhibitors: Alkali	Chromate	Silicate	Organic	Exper.	Per cent corrosive wells treated
A	62	62	9	1	21	0	0	2	1	38.7
B	153	10	0	0	0	0	0	2	0	20.0
C	67	-	0	0	0	0	0	0	0	0
D	7	7	0	0	4	5*	0	2	1	100
E	75	75	0	3	0	8*	1	12	1	18.7
F	34[1]	34	2	8	0	0	0	0	0	0
G	37	1	0	0	0	0	0	1	0	100
H	46	46	0	1	0	0	0	26	0	56.5
I	185	145	4[2]	47	32	4	46	0	0	56.5
J	96	66	4	1	33	0	4	1	0	57.5
K	27	0	0	0	0	0	0	0	0	0
L	99	20	0	0	0	0	0	0	0	0
M	52	-	0	0	0	0	0	0	0	0
N	10	0	0	0	0	0	0	0	0	0
O	60	18	9	0	0	0	0	0	0	0
P	9	8	1	0	0	0	0	0	0	0
Q	47	38	11	0	0	1	0	15	0	42.1
R	300	200	1	0	20	0	0	40	0	30.0
S	172	35	3	1	0	0	0	3	0	8.5
T	94	46	0	0	1	38	0	2	0	89.0
U	82	11	0	0	0	0	4	0	0	36.3
V	61	14	0	5	0	0	0	0	0	0
W	280	43	1	0	0	1	0	31	0	74.3
X	9	9	0	0	0	9	0	0	0	100
Y	49	44	6	2	0	0	20	0	7	61.5
	2113	932	51	69	111	53	75	137	10	

* Discontinued.
[1] Twenty-seven of these wells contain hydrogen sulfide.
[2] Two of these wells are equipped with nickel plated tubing.

*Presented at the 29th Natural Gasoline Association of America Annual Convention, April 24-26, 1950, Texas Hotel, Fort Worth, Texas.

†Sun Oil Company, Beaumont. Chairman, NGAA Corrosion Research Project Committee.

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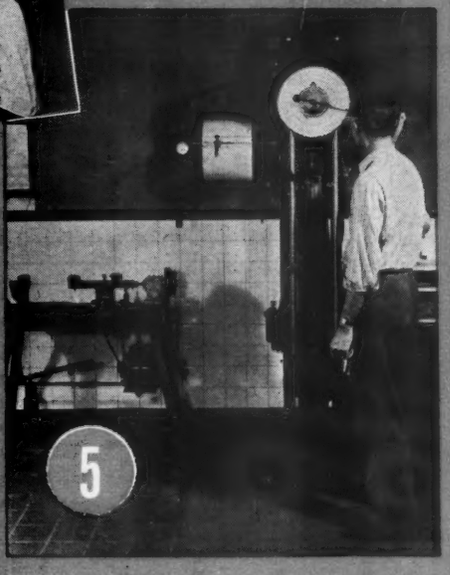

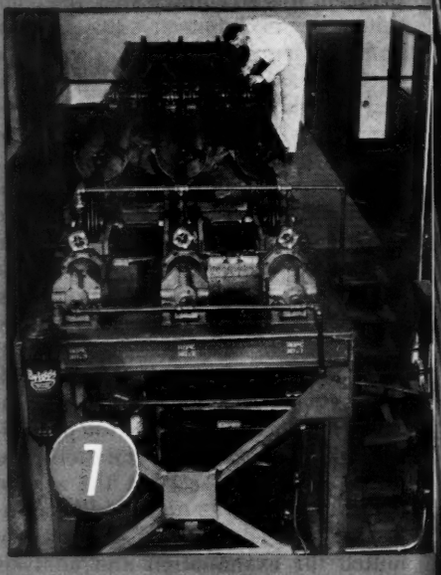

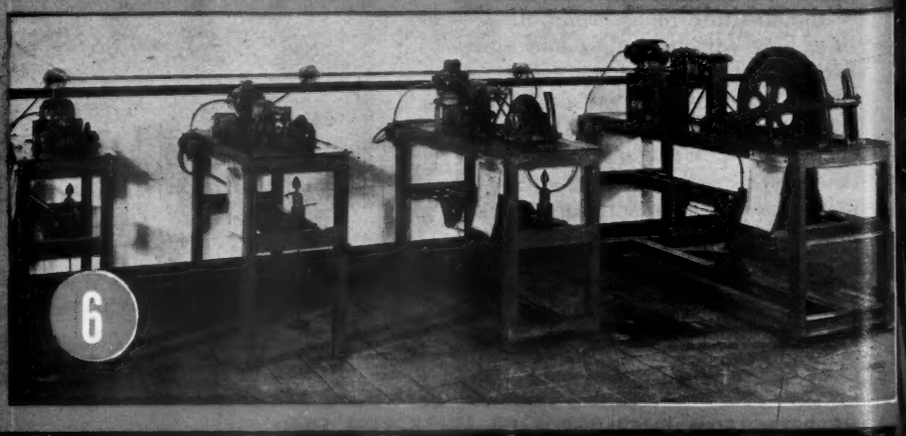

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3. Rope Testing Machine. This 3-story high machine is designed to test and record the breaking strength of the rope when finished and ready for the customer.

4. Chemical Analysis Laboratory. Steel for Union Wire Rope is made to rigid specifications. Here rods and wires are chemically analyzed to make certain that the correct combinations of carbon, manganese, etc., are kept under control.

5. Wire Tensile & Torsion Tester. In tension and under torsion, this machine tests wires to see that they measure up to the extraordinary high level of strength and toughness mandatory in Union Wire Rope.

6. Wire Fatigue Testers. The fatigue strength of wire rope is the sum total of the fatigue strength of the wires in its construction. Here, the wires in tension and bending are tested for fatigue strength.

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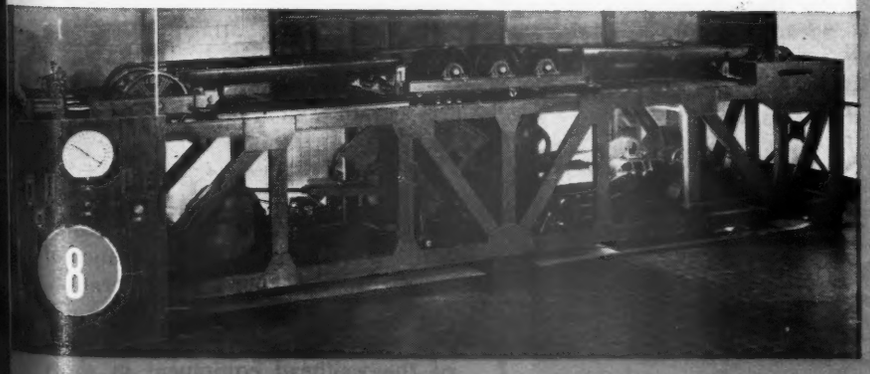
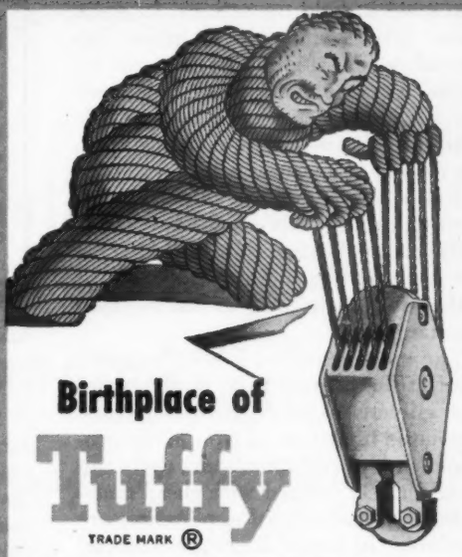
After Union Wire Rope designs pass all of the exhaustive testing imposed by this array of highly specialized laboratory equipment and technical experts, Union Wire Rope engineers submit it to the final test. In the field, under actual working conditions, they confirm the longer life expectancy indicated by laboratory findings and determine proper application which in itself is vitally important.





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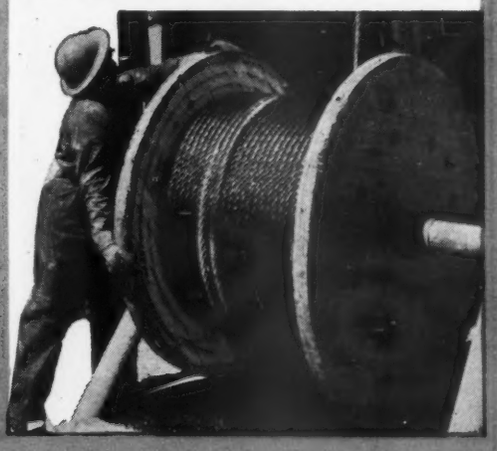
It is made for two operations—jackknife and standard rotary drilling. This simplifies ordering and delivering to you the proper grade of steel and construction to give you the ultimate low-cost rotary drilling line. There is no need to be confused with former complicated specifications. Just remember the name Tuffy. To write a typical order is as simple as this:

2500 feet, 1⅛ inch Tuffy Rotary Jackknife line, or 2500 feet, 1⅛ Tuffy Rotary Standard line.

Write today for an "in-person" presentation of full data.



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chromate in field operations. In some cases, severe plugging of tubing occurred when this material was injected. Various amines, bone oil, sodium silicate and some of the organic inhibitors have been used with varying degree of success.

In the case of sodium silicate, it has been reported to the committee that in addition to having some degree of success in mitigating corrosion, it also sealed off the thread leaks in the tubing string.

The most extensive inhibitive treatment at the present time is with commercially available organic inhibitors. A notable reduction of iron in the produced waters indicates some wells can be effectively treated with these materials. Two methods of application are available. In liquid form the material is pumped into the annulus. In stick form the material is lubricated into the tubing and allowed to drop to bottom.

Soda ash, sodium bicarbonate, sodium hydroxide, potassium carbonate and some of the above in combinations are being used with efficiencies of 80 to 100 per cent reported. These percentages are based on iron content of water before and after treatment.

As of November 30, 1949, twenty-nine operators reporting to the committee listed a total of 2113 gas condensate wells with 932 considered as corrosive. At that time 41.42 per cent of these wells were being chemically treated. H. E. Waldrip's subcommittee is responsible for these statistics, (Table 1). Treatment costs range from 20 cents to $1 per 1,000,000 cu ft of produced gas.

Oil Supplies in War

During World War II, the Pacific Ocean area required 22 million barrels of petroleum products monthly. The Iwo Jima campaign alone, for instance, used enough fuel to fill a train of railroad tank cars 238 miles long and enough drummed lubricating oil to fill 125 box cars. This is only an indication of the tremendous demands made on the American petroleum industry by the armed forces of the United Nations—demands that were fully met on all fronts at all times.

These figures indicate the reason oil resources are a prime objective for any nation that may conceivably participate in a future war.

Coatings

Several operators have installed strings of coated tubing in known corrosive wells. This coating comprises several coats of baked-on plastic type material. The data on this form of mitigation available to the committee indicates effective mitigation in most cases. Improved application techniques, particularly on the pipe ends and collars have apparently eliminated one of the weak spots in this method. Continued caliper surveys and other checks will further determine efficacy of this treatment.

Alloy Tubing

Laboratory tests indicated at an early date that some of the alloys, particularly chromium and nickel, were resistant to this type of attack. In concentrations of 9 per cent and up, little or no evidence of corrosion was found. In lower concentrations the nickel alloy showed some attack. However, in the NACE field tests, 5 per cent nickel appeared to be on the border line and possibly effective under mild conditions.

The problem of obtaining an alloy with satisfactory physical characteristics was finally overcome by manufacture of the tubing by the mills and application of special threads on the pins and boxes by a separate fabricator.

The first string of nickel alloy tubing was delivered and run about two years ago and has been closely checked at frequent intervals up to the present time with excellent results so far. Waldrip's subcommittee reports that to date 51 strings of nickel alloy tubing have been installed. These installations are being closely watched and checked by the individual operators. It is the usual practice to run a caliper survey when the string is installed for basis of comparison with later runs to determine if corrosive attack is evident. As yet, we have had no indication of measurable attack reported on these strings.

Conclusion

Though it is yet too early for the committee to state any definite conclusions, I feel that sufficient data is at hand to predict a solution of the gas-condensate corrosion problem. In a number of wells presently being treated successfully and economically by injection of inhibiting agents, the practice will doubtless continue. As time goes on new wells are completed in known corrosive areas the use of alloy tubing will increase.

It is reasonable to believe that with continued widespread use of these alloys that the present cost will be appreciably lowered. This naturally would encourage their use in greater quantities.

One very important function of the NGAA committee is the interchange of information on the performance of equipment and methods of operation. Reporting on the performance of different alloys allowed us to take care of the wellhead equipment in short order. Comparison of results on inhibitors and neutralizers made it possible to define the proper field of application for the various treatments.

* * *

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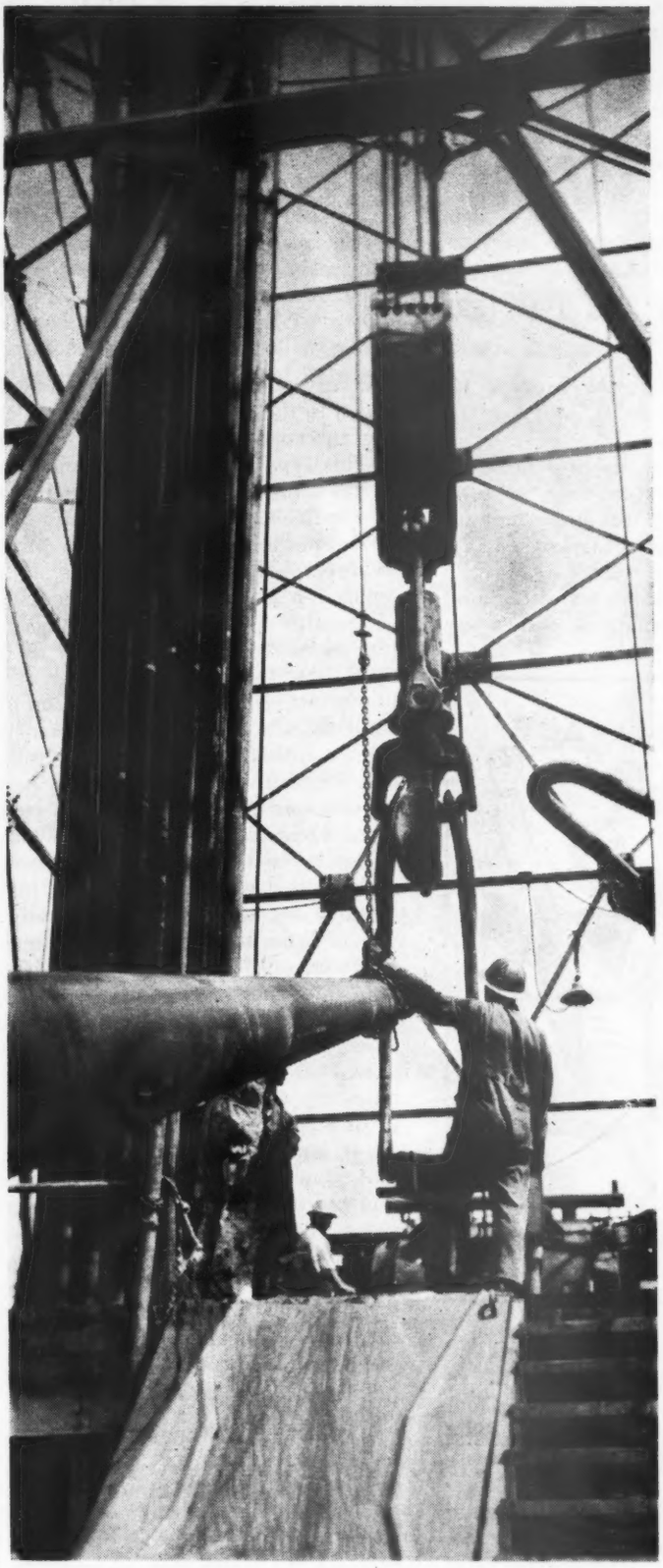

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Introduction to

Radioactivity Well Logging†

R. B. DOWNING* and J. M. TERRY*

RADIOACTIVITY well logging is by far the most interesting of all oil field services, as it produces results which approach the supernatural and are actually phenomenal.

As in the case with any technical service, you, the user, are a bit reluctant in accepting this outstanding geological aid for fear of becoming involved in something with which you are not familiar. In fact, we may go so far as to say the average layman postpones the reading of scientific material, prepared in the usual manner, because of its dryness and longhaired characteristics. This explains why the majority of geologists, petroleum engineers and other interested oil field personnel are not as well versed in the subject of radioactivity well logging as they should be, and, as a result these men are laboring under a false impression.

The basic theories and principles underlying a combination radioactivity well log are actually quite simple, and even though you, as a reader, may not be technically trained, the phenomenon is readily understood and may be explained in simple language.

Radioactivity well logging was developed by a group of scientists known as Well Surveys, Inc., in Tulsa, Oklahoma. After a period of extensive experimenting and field testing, the Lane-Wells Company was licensed to expedite and offer the service to the oil industry. The first commercial gamma ray log was run in the summer of 1940 and since that time over 25,000 successful logs have been completed throughout the oil producing areas of the United States.

As we have come to know the service today, a combination radioactivity well log is comprised of two parts, a gamma ray log, which accurately identifies stratigraphy or geologic formations, and the neutron log, which indicates possible fluid filled porous zones in sandstones and limestones. With this type of information available it is simple to make a proper interpretation of the log, and without any additional data the average recompletion problem is well on the way to solution.

The above facts, as presented, do not create an outstanding achievement, as much of this important information may be obtained by various other means, such as—an electrical log, sample determinations, time log, mud analysis and many

home-spun methods, but are obtainable only during the actual drilling of the well.

It may be recalled that in the early days of rotary drilling, the above mentioned geological aids were not available or were disregarded in the mad rush to reach the primary objective in order to cash in on the early flush production, and very little attention was given to possible pays that were unknowingly passed up and cased off. As an outstanding example, many wells in the greater Seminole Area of Oklahoma were drilled to the prolific Wilcox sand with no regard to highly profitable upper pay zones, many of which would have produced oil in commercial quantities. In addition to the lost geological information, inaccurate measurements, crooked holes, and very poor casing records have all added to the impossibility of completing an economical remedial program on this type of well, and the mission is still a lost cause unless a combination radioactivity well log is employed to regain the necessary data for proper recompletion. It is now possible to obtain a permanent record of geological conditions behind multistrings of pipe as easily and as accurately as in open hole. Generally speaking, the immediate environment surrounding the subsurface recording instrument has no apparent effect on the results, and identical log characteristics may be obtained in either cased or open hole. Logs recorded in void bore holes, or in those partially or completely filled with various fluids, may be superimposed—one upon the other—with little or no change in pattern. Common well fluids, such as fresh or salt water and mud composed of various conditioners, including oil based mud and oil or gas, have no apparent effect on the log which eliminates all well conditioning necessary prior to the running of an electrical log in many areas.

A gamma ray log, or a combination radioactivity survey, not only regains lost geological information from wells which have been drilled and cased, but is also a valuable record on a new well, supplementing the electrical log particularly under adverse bore hole conditions.

The Gamma Ray Log

As the gamma ray log was the first to be offered as a service, let us discuss the simple theory and principles underlying the recording of the log. It has been known since the advent of nuclear physics that all geological formations contain varying amounts of radioactive material, depending upon their individual characteristics. This unusual fact was recognized as the result of laboratory experiments but was not put to practical use until a relatively short time ago. Even though there are radioactive elements in all rocks, the fact until analyzed means very little to the non-technical person engaged in the oil business, and the first step in the analysis is to

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*Lane-Wells Company, Oklahoma City, Oklahoma.

determine why radioactive material is so important and to form a mental picture of just what it is. To eliminate the highly technical definition of radioactive material, we will boil it down to a few simple words and say that it is a substance having a tremendous amount of stored energy which is being continuously released through natural processes; in other words, breaking down, being consumed or being expended by disintegration and after a period of time it reaches a point when all of its energy has been spent and no further activity is indicated.

A direct comparison of radioactive energy may be made to something which we can all visualize by igniting a piece of wood and watching it burn. During the process of burning, the wood is releasing stored energy in various forms, such as heat, light, smoke and other gases, and after it has been consumed, after all of its energy has been expended in the above forms, we have a residue of ashes. (Fig. 1.)

If we had several different kinds of wood burning at the same time, it would be a simple matter to identify the various types of wood by the odor of their smoke, such as pine, hickory, oak, etc. During the period of burning, or disintegration, they are giving off natural, tell-tale clues to their identity. Radioactive material is comparable to the burning of wood as during its process of deenergizing, it also releases certain physical factors which may be identified.

Referring to Fig. 2, we see that radioactive material releases Alpha particles which travel a very short distance—a small fraction of an inch, and may be shielded by one thin sheet of bond paper.

Beta particles are also released and have much the same characteristics as the Alpha particles, in that they travel a very short distance and can be confined by three or four sheets of cardboard. Obviously, these two forms of released energy are useless for recording purposes and may be disregarded. In addition to the two mentioned particles, some radioactive material radiates gamma rays in great quantities and these rays are so powerful that they have been detected through 12 in. of solid steel, as well as 8 in. of pure lead. After a quantity of radioactive material has expended all of its energy by releasing Alpha and Beta particles and gamma rays, together with associated radioactive gases, the final residue is lead—shown in Fig. 2.

It logically follows that if gamma rays have such penetrative qualities and are present in all geologic formations, they can easily be recorded through multi-strings of casing and offer a comparatively simple means of identification.

FIG. 1

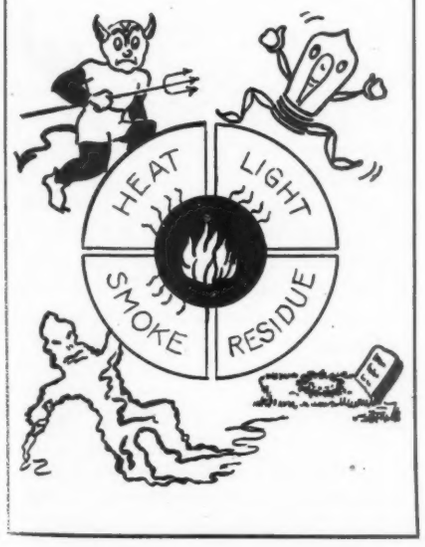


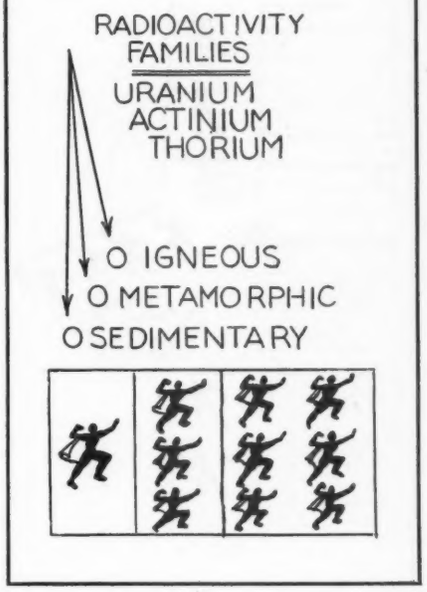
FIG. 2

The disintegration of radioactive material and the burning of wood are quite similar; both processes release energy in different forms and at least one of these forms may be identified. In the case of burning wood, the time required to reach the end point of ashes is relatively short, but with radioactive material in the earth's crust, the time element is considerably longer as the half life of radioactive substances found in formation samples is as high as 2,000,000 years.

Origin of Radioactive Material

Referring to Fig. 3, you will note that three common elements furnish the major portion of the radioactive material found in the three main classifications of geologic rocks. Upon reviewing our elementary geology, we recall that primary, sedimentary and metamorphic rocks are the result of erosion of igneous rocks and their composition may be traced to their original source material. In order to eliminate considerable unnecessary and unrelated geological discussion, we concede that all geologic formations contain relative amounts of radioactive material, regardless of type or character.

FIG. 3



A most interesting and helpful coincidence reveals itself as we refer to Fig. 3. It is noted here as a generality, that regardless of the classifications of the rock, as it becomes darker in color it also becomes more highly radioactive in character. This fact does not prove true in all cases but is the rule rather than the exception and may be used to advantage in some areas where detailed interpretation is required.

Because both experience and geology have taught us that petroleum is most generally associated with sedimentary rocks — in origin and accumulation, we will confine our immediate attention to the three most common sedimentary formations; namely, limestones, shales, and sandstones.

Hypothetical Curve

Referring to Fig. 4, you will note that a hypothetical curve has been plotted opposite a sequence of limestone, shale, and sandstone. You will also notice, at the very top of the sketch, that recorded radioactivity increases to the right, as indicated by the arrow. These measured increases in radioactivity could have been as

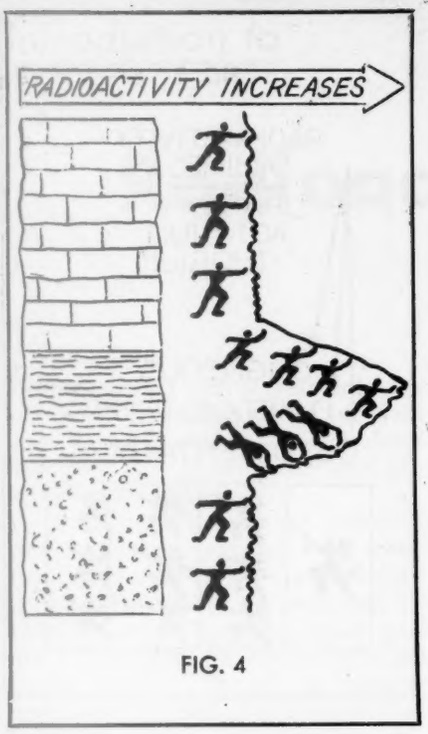


FIG. 4

easily indicated to the left but, usually, graphic representations of higher values are plotted to the right, a technical practice of long standing.

The topmost formation shown in Fig. 4 is a limestone and contains a relatively small amount of radioactive material, which in turn radiates its proportional share of gamma rays. These gamma rays have been pictured as "Supergams" and these "Supergams" are exerting force on the curve causing it to be pushed to the right. For comparison, the limestone section has arbitrarily been given three "Supergams" to influence the curve. Underlying the limestone is a shale bed which contains considerably more radioactive material; consequently, it radiates many more gamma rays and the additional force of these rays causes the curve to extend much further to the right. We have more "Supergams" pushing on the curve all through the shale formation and the added energy is reflected in a much higher reading.

The sandstone formation at the base of the columnar section indicates a decrease in radioactive material, as the curve has returned to its original position—similar to that opposite the limestone. Here we see only two "Supergams" exerting force on the curve end; theoretically, a sandstone should show a lower value than a limestone but in actual field practice it is impossible to differentiate accurately between a limestone and a sandstone on a gamma ray log without other information. By laboratory analysis, most limestones are slightly more radioactive than sandstones, as shown by the relative number of "Supergams" in Fig. 4, but the difference in value is so small that for all practical purposes they record within the same range of intensity. On the other hand, any shale—regardless of its type or character, is more highly radioactive than either limestones or sandstones and may be easily identified on the average log without the aid of other data.

Because of the normal sequences of geological deposition, we rarely find a limestone in direct contact with a sandstone but these formations are usually separated, or interbedded, with shales. For this reason we are able to identify easily the shale breaks on a gamma ray log and, with a reasonable knowledge of the local stratigraphy, the low value readings may be interpreted as either limes or sands or gradational zones, depending upon the relative position of the curve.

It must be remembered that all formations contain some radioactive material and for that reason there can be no zero value on a gamma ray log. All readings are positive and are relative, depending upon their radioactive strength, which simplifies interpretation and allows the average layman to become an expert on log correlation. As this paper deals only with the theory of radioactivity well logging, no attempt will be made to discuss interpretations.

Radioactivity of Rocks

The relative amount of radioactive content of some of the most common formations is graphically represented in Fig. 5.

Coal, one of the lowest radioactive substances, is the outstanding exception to the color clue referred to in Fig. 3, it being black and yet very low in radioactive value. The thick section of salt, common to West Texas and Kansas, is slightly more radioactive than coal but less than either dolomite, limestone or sandstone. For all practical purposes, these three formations, dolomite, limestone and sandstone, may be considered as having approximately the same intensity and, on a log, they will record the same value within reasonable limits. It follows that a shaly limestone or shaly sandstone will be more radioactive than either a pure lime or sand because of the radioactive properties of the contaminating shale.

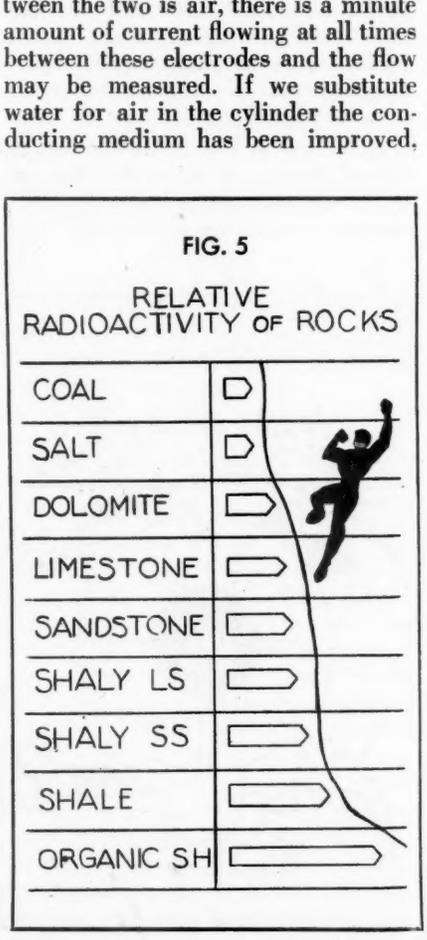
As a general rule, all shale is more radioactive than any of the formations shown in Fig. 5, with the exception of organic shale which is usually black and exceedingly high in radioactive content. Two well known examples of organic shale are the Woodford section of Oklahoma, which overlies the Hunton limestone, and the Heebner shale of Kansas, a widespread thin black shale identified 35 to 100 ft above the Kansas City limestone. Both of these organic shales react with sufficient intensity to require recording on second or third beam, which means that it exceeds the limits of the normal logging scale by two or three times. Two second beam shales are shown on the gamma ray log in Fig. 9.

In order to make use of this radioactivity phenomenon for commercial purposes, it was necessary to devise some method of measuring and recording the relative amounts of radioactive material in various formations encountered in a bore hole.

Electrical Circuit

By laboratory experiment it was found that by employing the most elementary of electrical circuits the problem could be solved. Referring to Fig. 6, we see this simple circuit represented by a storage battery, which supplies the current; an ammeter, which measures the flow of current; and two insulated electrodes in cylindrical form. One electrode passes through the center of the cylinder and acts as a conductor of current, while the metal cylinder itself is the other electrode. Even though these electrodes are not in contact with each other and the insulating medium between the two is air, there is a minute amount of current flowing at all times between these electrodes and the flow may be measured. If we substitute water for air in the cylinder the conducting medium has been improved.

FIG. 5



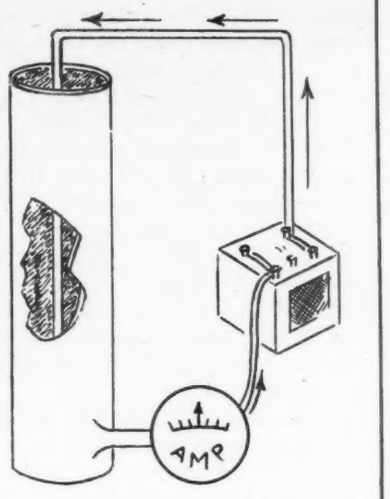


FIG. 6

and with no change in the power supply more current will flow through the water than through the air, as it is a better conductor of electricity. Further improvement of the medium may be made by adding salt to the water and an additional increase in current flow will be indicated on the ammeter. It follows that when the two electrodes are in direct contact, we have a short circuit and the maximum amount of current passes through the water.

Along with many other strange things known by physicists is the fact that there are certain gases which have the ability to conduct electricity by a phenomenon known as ionization. Thus the gas conductivity increases in direct proportion to the amount of ionization. This is useful because one means of producing ionization is to subject the gas to bombardment by gamma rays, which is easily and conveniently done by placing the gas chamber adjacent to various geologic formations, which are continuously releasing gamma rays.

As we previously discussed, electrical current will flow between two insulated electrodes. As the gas medium surrounding the electrodes is rendered electrically conductive by ionization, the flow of current increases. Our problem is solved by filling the cylinder in Fig. 6 with gas and supplying an adequate current, together with certain requirements and suitable amplifications. We now have a subsurface instrument which will be influenced by varying amounts of gamma ray bombardment from geological formations.

When the instrument is in the environment of a formation containing a small amount of radioactive material such as sand or lime, few gamma rays are being radiated to bombard the confined gas; consequently, very little ionization is present and the flow of current within the ionization chamber is at a minimum. This condition is recorded as a low value on a gamma ray log.

As the instrument approaches or is surrounded by a more highly radioactive formation, shale, there are many more gamma rays available for bombardment of the gas, producing a higher state of ionization which permits more current to pass between the electrodes. On a gamma ray log, such increases in radioactive content are indicated by the curve moving to the right as shown in Fig. 4.

Gamma Ray Subsurface Instrument

Fig. 7 pictures a gamma ray subsurface instrument which measures 3⅜ in. in diam and is about 10 ft long. The lower 3 ft is the ionization chamber and contains the electrodes and the inert gas under pressure. The top section of the instrument houses the power supply in the form of high voltage dry cells and also an amplifying system similar to the one in your home radio. It is necessary to provide subsurface amplification to the measured flow of current as the amount is so minute it would be completely lost before reaching the surface without assistance. The subsurface instrument is controlled by means of a reverse concentric, single conductor wire line cable, operated by means of a hoist truck as indicated in Fig. 8.

Typical Field Set-Up

A typical field set-up is pictured here (Fig. 8), including a bore hole sketch showing the various formations with the subsurface instrument in position.

On the surface there are two trucks, a hoist unit and a recording or instrument car, which are communicative by means of a connecting cable.

FIG. 7

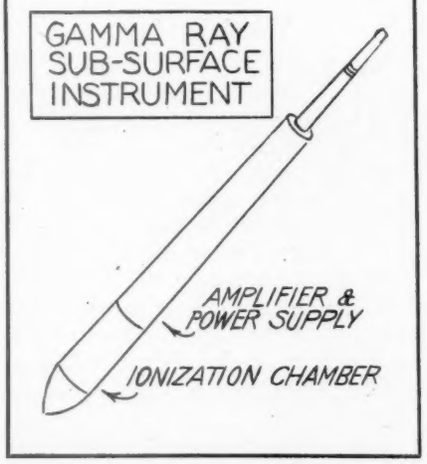
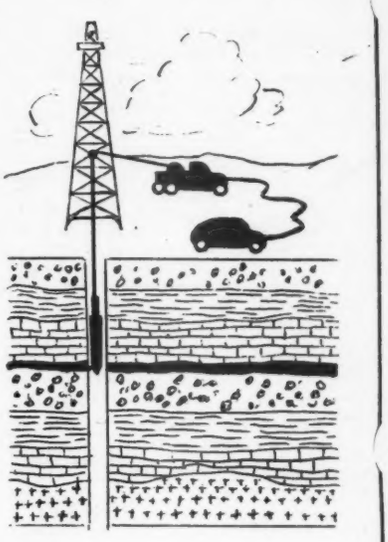


FIG. 8



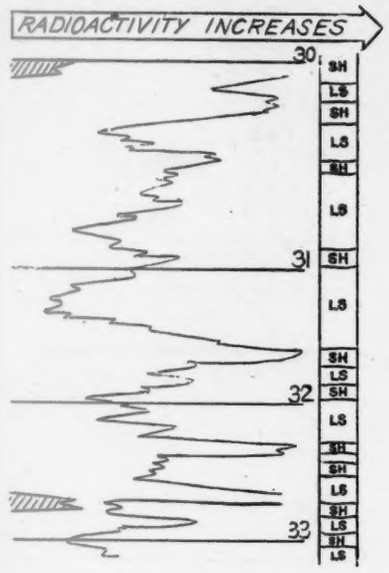
General Logging Practice

The subsurface instrument is lowered to the total depth of the well to check measurements and the log is obtained on the upward trip of the instrument. Hoist speed varies from 20 to 70 ft per min, depending upon the type of instrument in use; either the gamma ray or neutron log may be recorded on the first run.

Summarizing the behavior of the log as the subsurface instrument is retrieved from the hole, we note that the recording pen on the Speedomax recorder varies in position, depending upon the radioactive value of the formation immediately opposite the subsurface instrument. Starting from the bottom of the bore hole, in Fig. 8, the deepest formation is some form of igneous rock and in all probability will be above average in radioactive content. This being the case, when the ionization chamber is in position to be influenced by gamma ray radiation from this formation, the recorded value will be relatively high. Reviewing the basic theory, it is readily seen that this is a natural function because the amount of current flowing between the electrodes in the ionization chamber is dependent upon the intensity of the gamma ray bombardment of the confined gas.

As the instrument enters the limestone section immediately above the igneous material, the bombardment is less severe because limestone is very low in radioactive content; consequently, there is a minimum of gamma rays available for bombardment. This condition is recorded as a

FIG. 9

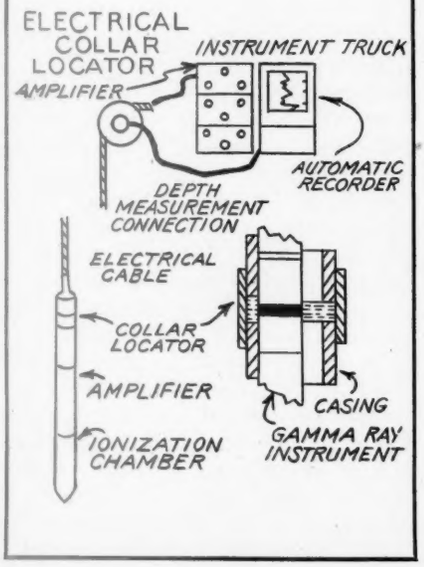


low reading on the gamma ray log. A shale bed overlies the limestone and as the instrument surveys this formation, the readings will again increase as the result of added gamma rays for bombardment of the ionization chamber.

The next formation, a sandstone, will also record as a lesser value due to its slow radiation of gamma rays, but the comparatively thin section of black shale in contact with the sandstone will undoubtedly be a very high value and will require at least second beam recording.

The limestone adjacent to the instrument, shown in Fig. 8, will be indicated as a minimum value on the gamma ray log in contrast to the overlying shale bed containing a much higher percentage of radioactive material. The surface formation, a sandstone, will record a normal low value.

FIG. 10



Type Log

Fig. 9 illustrates a portion of a combination survey taken from a well in Kansas. The indicating arrow at the top of the log again tells us that radioactivity increases to the right. Maximum peaks on the curve may be immediately identified as shale breaks, while minimum values, to the left of the page, are either limestone or sandstone. In order to make an accurate differentiation between sand or lime from a gamma ray log, it is necessary to be familiar with the local stratigraphy, or have the advantage of other well information for comparison. It is most reasonable to assume that in a given field there is such information available even though the individual horizons will not be logged in the same identical subsurface position from well to well. In the majority of such cases sufficient formation continuity will be present so that a definite correlation may be made between a well with adequate geological information and one that has been logged by means of a radioactivity survey. When the objective is to obtain geological information not recorded during the original drilling of the well, the data is successfully and efficiently regained through casing. Radioactivity well logging is the only known method by which such a feat can be accomplished and it is within easy reach of all who need such a service.

The detailed interpretation, as shown in the geologic column on the log (Fig. 9), is the result of experience in the use of gamma ray logs combined with a general knowledge of the area, and after a short period of usage, the average geologist, petroleum engineer, or production man becomes an expert in radioactivity well log interpretation and correlation.

The Collar Log

The collar log is a record of the exact position of each casing collar and is recorded by means of a collar locator, usually run in conjunction with the gamma ray instrument. The collar log and gamma ray curve are recorded simultaneously and on the same chart. This service provides a permanent record of the fixed relationships of the collars to the formations. With the collar located, the top and bottom of formations are accurately established in relation to the nearest collar.

Illustrated in Fig. 10, the subsurface collar detector unit used with the gamma ray instrument is placed between the instrument and the cable head. It utilizes a magnetic field and associated electrical circuits to indicate the location of a casing collar. When this subsurface detector passes a casing collar, an electrical impulse is generated. This impulse, through the amplifier unit, actuates the pen on the surface recording unit which indicates the collar located on the log. On the standard log form, collars are indicated by short horizontal lines which appear near the depth mark in the center of the log.

Collar logs are useful in selecting the correct depth for setting bridging plugs, packers and cement retainers. Knowing where the collars are located, the operator can better determine the best place to set these tools with greater assurance of obtaining the desired results.

The Neutron Log

With the problem of formation identification solved by means of the gamma ray log, it became necessary to supplement this data with additional information relative to producing horizons. The neutron log is capable of indicating possible fluid bearing porous zones in limestones and sandstones, which completes the project of obtaining a workable record of formation conditions — in open or cased holes.

The theory of the neutron log is equally as simple and understandable as that pertaining to the gamma ray log, but is much more complicated unless explained in layman's language. Processes other than natural occurrences are necessary in obtaining a neutron log and, from a purely scientific viewpoint, involve many more

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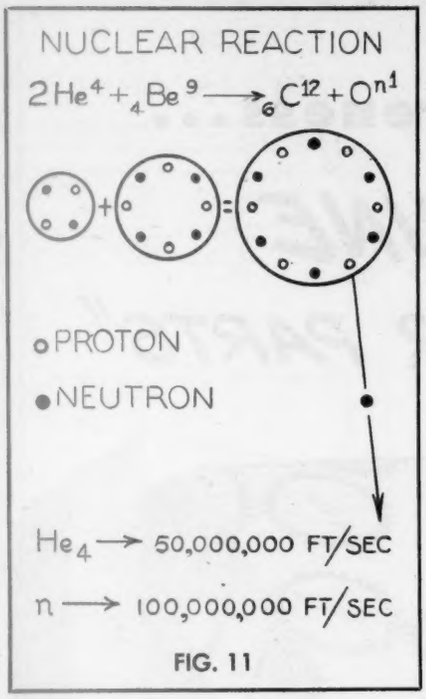


FIG. 11

conditions which require precision control.

Experiments in nuclear physics reveal that if any geological formation is subjected to bombardment by a source of neutrons, this bombardment causes the formation to radiate additional gamma rays other than those emitted from the radioactive material contained in the formation. Gamma rays which normally radiate from a formation may be said to be primary gamma rays, while those which result from neutron bombardment are classified as secondary gamma rays. In the procurement of a neutron log we are dealing with secondary gamma rays.

The source of the neutrons is both interesting and important. It is known that if certain radium salts are combined with beryllium, the nuclear reaction produces neutrons in great numbers. Referring to Fig. 11, we note that helium four (He_4) combined with beryllium nine (Be_9) forms carbon twelve (C_{12}), and an extra neutron. Helium four (He_4) happens to be an Alpha particle, one form of released energy in the disintegration of radioactive material (Fig. 2), while beryllium nine (Be_9) is one derivative of the element beryllium. These two energized substances collide with terrific speed during the process of neutron development, or at the rate of 50,000,000 ft per sec, and after the successful violent impact takes place, the resulting neutron leaves the site of collision, traveling about 100,000,000 ft per sec.

This information as presented above, both in chart and written form, is highly technical and of very little interest to the majority of neutron log users, but it is helpful to have at least some idea of how the theory of the neutron log is applied in actual practice.

Fig. 11 is much too technical to remember and is not important in the use of a neutron log, but some idea of the origin of neutrons should be retained; consequently, if you will refer to Fig. 12, we have the same story in much simpler language and it is readily understood. All of the pertinent factors of Fig. 11 are shown here; the union of Raymond Radium and Bessie Beryllium—and as a result of this nuclear nuptial, we have our little Neutron. Careful study of Fig. 12 reveals the all important time element necessary in the development of neutrons, as we have the desired product immediately following the marriage of Raymond and Bessie.

Before leaving this portion of the discussion, let us again review the principles employed in obtaining a neutron curve. Assume we have a body of limestone in a well bore, which is indicated on the gamma ray curve as a very low value because limestone contains very little radioactive material; again, assuming this limestone is dense with no porosity, we introduce a source of neutrons into the bore hole so that these neutrons may bombard the limestone. As a neutron leaves the source and comes into contact with the formation, a secondary gamma ray is released, one that would not have radiated without the assistance of the neutron. Under these conditions, the limestone is radiating both primary and secondary gamma rays, the former in small quantities by natural disintegration, the latter in much larger numbers as the result of neutron action.

The object of the neutron log is to determine possible porous zones in sandstones and limestones and the action of the neutrons is dependent upon the condition of the formation. In a non-porous sand or lime the path of the neutrons to the formation is unobstructed due to the absence of hydrogen, and a very high percentage of the neutrons produce secondary gamma rays, as they have met with little interference. These secondary gamma rays are being recorded in the same manner as the primary rays on a gamma ray log—and when the neutron bombardment of the formation is efficient, the curve is influenced to the right, indicating a high gamma ray value.

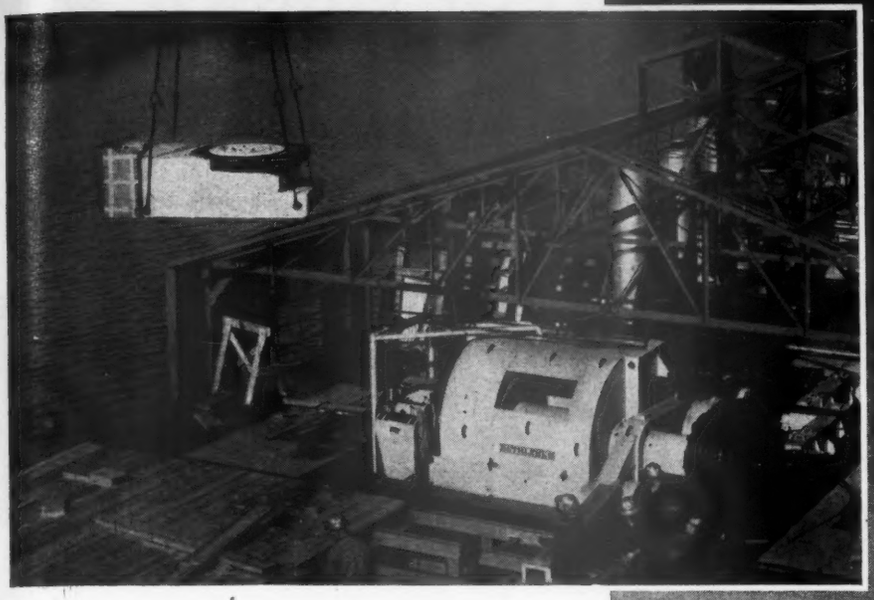
Fig. 13 pictures little Neutron rushing to the formation to release a Super-Supergam, (secondary gamma ray), which he successfully accomplishes. After little Neutron has completed his mission, he expends himself while Super-Supergam is well on the way to the ionization chamber to be recorded.

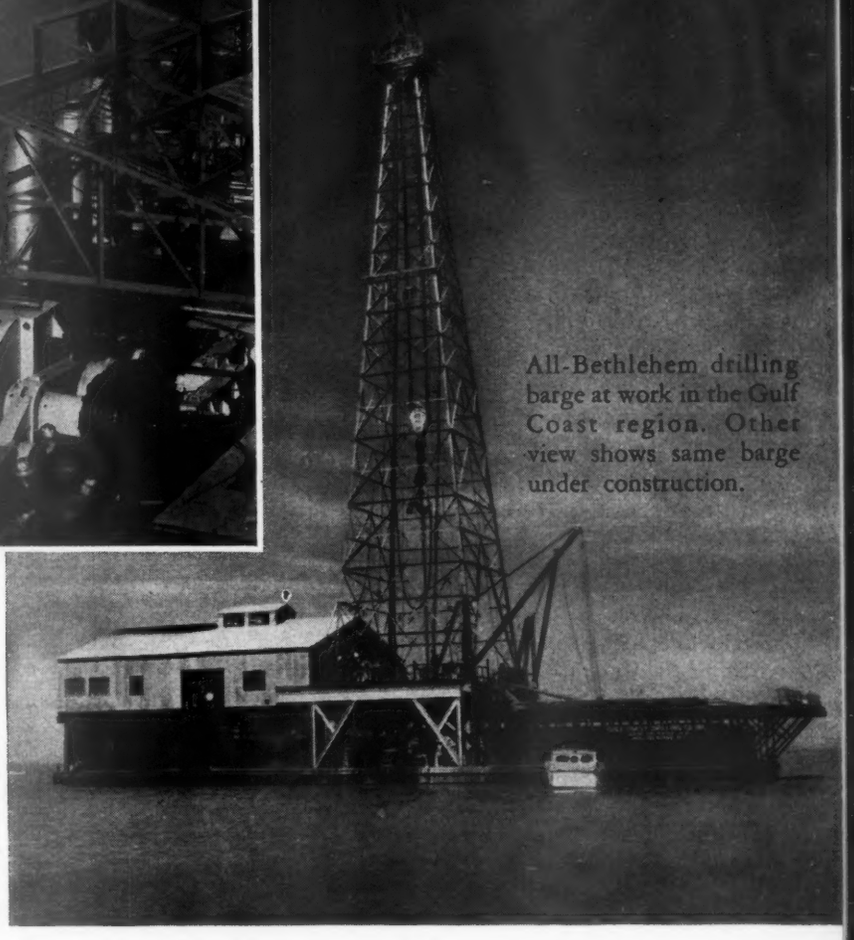
It so happens that a neutron has approximately the same mass as a hydrogen nucleus, which affects the behavior of a neutron when a porous formation is subjected to neutron bombardment.

Under normal conditions a porous formation will contain gas, oil or water, depending upon structural position, but in any event there will be hydrogen present. The hydrogen contained in gas, oil or water acts as a partial barrier, as a majority of the neutrons will collide with a hydrogen atom before reaching the formation. It is readily seen that if only a small

FIG. 12

FIG. 13





All-Bethlehem drilling barge at work in the Gulf Coast region. Other view shows same barge under construction.

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percentage of neutrons bombard the formation, there will be an equally small radiation of secondary gamma rays, which causes the curve to recede to the left, indicating a low value.

In Fig. 14, we see the same little Neutron with a bad case of the "eagers" on his way to release a Super-Supergam; however, in the top alley we find Harry Hydrogen about to put the "snatch" on little Neutron and, as a result, he never does get far into the formation. The same condition exists in the lower alley, where little Neutron is having hydrogen interference; but there are exceptions where even in the presence of hydrogen, the neutrons successfully bombard the formation, releasing secondary gamma rays.

Neutron Subsurface Instrument

The neutron subsurface instrument is practically the same as used in recording the gamma ray log with the exception of a few minor alterations. A sketch of the neutron instrument is show in Fig. 15. The neutron source in place is at the base of the instrument, shielded from the ionization chamber by an adequate thickness of lead. The ionization chamber is slightly smaller than that used in obtaining a normal gamma ray log, but the two subsurface instruments are essentially the same.

Fig. 9 represents the gamma ray portion of a radioactivity survey which, when combined with the neutron curve in Fig. 16, completes a combination log over a series of geological formations. Again referring to Fig. 9, immediately below 3100 ft in the interpretation column, a solid limestone section — about 60 ft in thickness, is indicated. This feature is obvious on the gamma ray log as the curve reflects a very low value over the entire zone "A".

FIG. 14

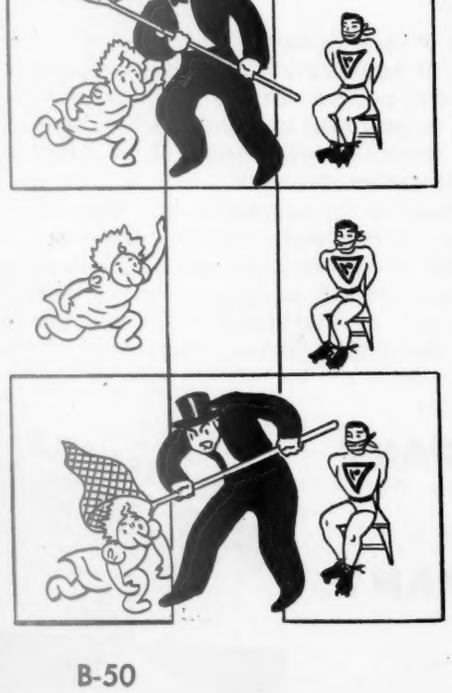


FIG. 15

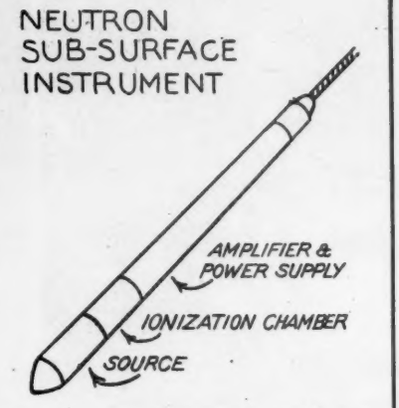
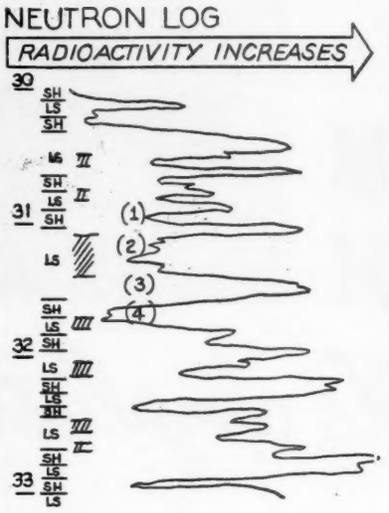


FIG. 16



The neutron log in Fig. 16 indicates that the top few feet of the limestone is non-porous, as the curve is deflected to the right to form peak (1); the neutron bombardment of the formation is complete with no hydrogen interference, causing a heavy radiation of secondary gamma rays. Peak (2) in Fig. 16 denotes possible porosity, as the curve approaches a minimum value because of gas, oil or water content. In this zone the neutron bombardment was much less effective due to the presence of hydrogen which in turn reduced the radiation of a major portion of secondary gamma rays, resulting in a low recording.

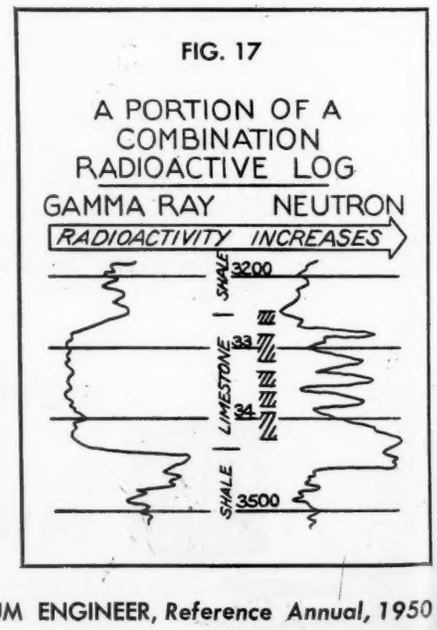
In the basal portion of the lime section, the formation again becomes dense or less porous, as indicated by the relative position of the curve to the right, peak (3).

It will be noted that on the neutron curve, peak (4), a shale records as a possible porous zone, but, obviously shale is impervious and as a general rule never produces gas, oil or water. As will be remembered, the neutron curve is influenced by the presence of the hydrogen atom and the average shale contains a higher percentage of connate water than either a porous sand or lime. All shales on the neutron log are so indicated and may be confused with porosity if the type of formation opposite the indication is not known. For this reason, it is advisable to make all detailed interpretations from a combination radioactivity survey, where both the stratigraphy and possible pay zones may be accurately correlated.

Multizone Limestone Reservoir

A typical example of a multizone limestone reservoir is illustrated in Fig. 17. The well is located in the Burton gas field of Kansas and the illustrated portion of the log covers the Mississippi limestone. From the gamma ray curve, the top of the lime may be picked at approximately 3260 ft with the basal limeshale contact at 3435 ft. Within this 175 ft of limestone there are five distinct and separate porous zones indicated by the neutron curve. The geological information obtained from the combination survey was checked by sample and time logs with not more than 1½ ft discrepancy in any of the subsurface datum points. Subsequent perforating of the casing revealed that the two lower zones were water bearing; the next two higher zones produced oil in commercial quantities and the top-most porosity is the wide-

FIG. 17



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34 joints — ⅞" "Oilwell" Grade "W" Rods
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100-inch strokes at the rate of 8-per-minute is the normal operating rate for this well; but peak polished-rod loads beyond 40,000 lbs. p.s.i. at 13 SPM were recorded by dynagraph.

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spread Chat, gas producing horizon of the Mississippi lime.

Many oil producing areas of the United States present similar conditions where multizones of upper pays have been cased off, and in many instances the individual horizon does not exceed 5 to 10 ft in thickness, particularly lenticular sandstones. It is important that these thin pays be accurately located to avoid unnecessary perforating and expense in the attempt to exploit uncertain zones. A combination radioactivity well log is the most efficient and economical solution to this type of production problem, regardless of the area, as the results are informative and entirely dependable.

Summary

Referring to the summary of the capabilities and limitations of each log in Fig. 18, we find that the gamma ray log measures natural or primary gamma rays, whereas the neutron curve records secondary gamma rays radiated as the result of neutron bombardment of the formation.

The appearance of a gamma ray log resembles the natural potential curve on an electrical log and the neutron log follows the general pattern of an electrical log resistivity curve. Regardless of the similarity of pattern, the basic theories of the radioactivity and electrical logs are entirely different.

A gamma ray log identifies formations, or stratigraphy, which is impossible on a neutron curve, and may be interpreted without additional information. It is necessary to supplement the neutron curve with other geological data since shales and porous sands and limes develop essentially the same type of "kick" and one could be easily mistaken for the other.

Type formations, such as highly radioactive shales or low value limes and sands, afford excellent markers for gamma ray log correlation. Correlation of neutron logs may be made on indicated porous zones in either sandstone or limestone.

It will be remembered that on a gamma ray log, shales are recorded as high values compared to low values on the neutron curve because of the high percentage of connate water in all shale.

Radioactive formations have a great effect on the gamma ray curve but the influence of these same formations on a neutron log is negligible. The diameter of the bore hole may change because of formation characteristics, but these changes are not reflected on a gamma ray log. Any appreciable change in bore hole diameter causes the axis of the neutron curve to shift; as the diameter of the hole becomes larger, the axis of the curve shifts to the right.

SUMMARY

	GAMMA RAY	NEUTRON
MEASURES	NATURAL	INDUCED
APPEARANCE	NATURAL POTENTIAL	RESISTIVITY
INDICATES LITHOLOGY	YES	NO
INTERPRETATION	ALONE	COMBINATION
CORRELATION	TYPE FORMATION	FLUID CONTENT
SHALE VALUE	HIGHEST	LOWEST
RADIOACTIVE FORMATION	GREAT EFFECT	NEGLIGIBLE EFFECT
HOLE DIAMETER	NO EFFECT	SHIFT CURVE
CASING	NO EFFECT	SHIFT CURVE
FORMATION FLUID	NO EFFECT	DEF. CURVE
BORE HOLE FLUID	NO EFFECT	SHIFT CURVE
POROSITY & PERMEABILITY	NO EFFECT	INDICATES ONLY POROSITY IN LIMES & SANDS

FIG. 18

In most areas, casing has no effect on a gamma ray log and it is impossible to determine from the log which portion of the hole is cased. On the neutron curve, there is a definite shift to the left as each string of casing is entered.

Fluids or gas within a formation are not indicated on a gamma ray log but are reflected on the neutron curve as possible porous zones. The gamma ray log does not indicate fluid levels within the bore hole as does the neutron curve. In running a neutron log, when the subsurface instrument leaves fluid and moves into the void bore hole, the axis of the curve shifts to the right.

There is no indication of possible porosity on a gamma ray curve, but it is the function of the neutron log to identify porous zones in sands and limes by means of the relative amounts of hydrogen contained in these formations.

Acknowledgment

The authors wish to thank the Lane-Wells Company for permission to publish this paper.

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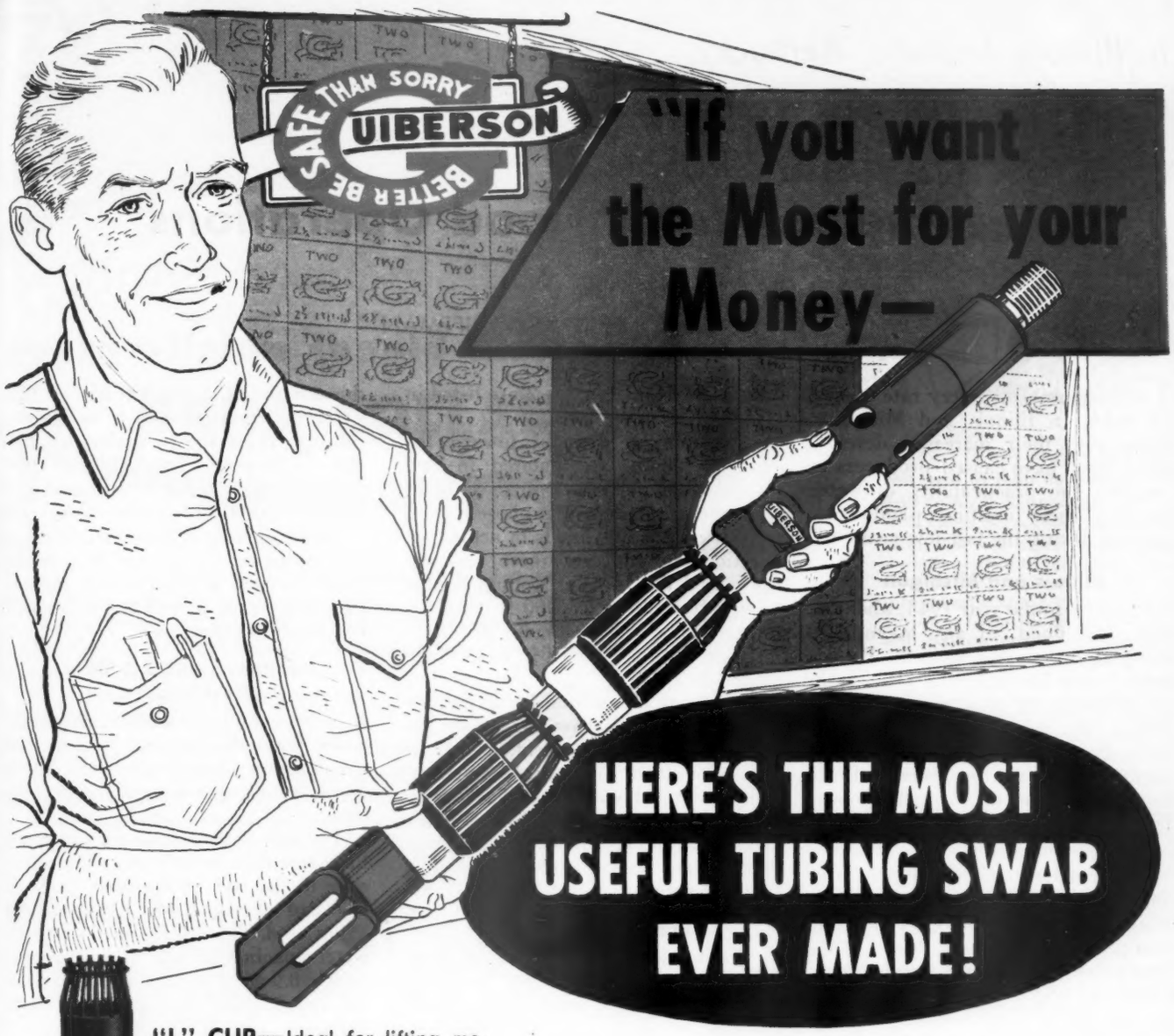

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Resume of Water Flood Operations*

R. R. VINCENT* AND K. P. HUFFMAN**

THE declining discovery rate of new oil fields in Illinois and Michigan, along with their increased development costs, have caused producers to consider the practicability of water flooding their existing productive acreage during the last few years.

Illinois and Michigan

Previous to the year 1943, when the first pilot flood, of any magnitude, was placed in operation in the Patoka field, water flooding was given little consideration by most operators. Following the success of this venture water flood activity has gained momentum until at the present time, there are a total of 33 active floods. This number includes 18 pilot and 4 dump floods.

For purposes of discussion, the state of Illinois was divided into three arbitrary geographical areas. The first area comprising the counties of Edgar, Clark, Coles, Crawford, Cumberland, Lawrence, and Wabash; the second, the counties of Clay, Edwards, Effingham, Gallatin, Hamilton, Jasper, Richland, Wayne, and White; the third, the counties of Bond, Clinton, Fayette, Franklin, Jefferson, Madison, Marion, Perry, St. Clair, and Washington.

Area 1, has 14 floods in operation with flooding depths ranging from 500 to 2600 ft. The operators, except in a few instances, are employing fresh water as the flooding medium, the supply source being gravel beds or shallow wells. Water treatment of some type, usually aeration and filtration, is employed. The 5-spot is the predominant flood pattern. Date for floods in Area 1 are listed in Table 1.

Area 2 has 14 floods in operation, 4 of which are dump floods. The word "dump" is used to designate a flood in which the pipe has been ripped, shot or perforated in an upper water zone in one or more wells, and a flood over which very little control is exercised. Data for floods in Area 2 are listed in Table 2.

Attention is directed toward the greater depths encountered in this area, ranging from 3000 to 3200 ft. The area contains one proposed flood.

Area 3 has five floods in actual operation. In addition, there are two proposed floods. The flooding depths range from 1410 to 1900 ft, with the 5-spot flood pattern again predominating. Data for floods in Area 3 are listed in Table 3.

The state has a total of 11 pattern floods that can be classified as past the pilot stage of development, and 17 in the pilot stage. There are three areas where dump flooding predominates.

At the present time, Michigan has no active floods, however, tentative plans have been made for one pilot development.

Present Day Trends

We would like to consider briefly the operators' present day thoughts concerning future water flood development.

In the past, operators generally used fresh water for flooding. In recent years, the trend is toward the use of a sub-surface supply, with the open type system giving way to the closed system. Water treatment is considered necessary in both systems.

The general trend has been to wider spacing between like wells with the conversion of alternate oil wells to injection wells.

An increasing number of floods are operating under some form of unitization, showing that operators are more carefully weighing the advantages all parties can realize when the prospective gains and risks are mutually shared.

Newly discovered fields are being considered as water flood prospects early in their productive life in order to realize a greater ultimate recovery through early water injection.

Future Prospects

On January 1, 1950, the API reserve estimate for the state of Illinois was some 468,000,000 bbl of oil. Of this amount, 134,000,000 bbl or 28.6 per cent was attributed to secondary recovery projects now underway. The state is currently producing 185,000 bbl of oil daily and it is estimated that at least 10,000 bbl is water flood oil.

As the number of floods increases, it is reasonable to assume that water flood oil will account for a greater percentage even though new fields will be found and developed.

Indiana, Kentucky, Ohio, West Virginia

Indiana. Indiana has had very little water flood development to date. To the authors' knowledge only three floods are in operation at the present time.

The only pattern flood on which we have any data is unusual, with reference to the rest of the area, in that, so-called alternate 440 ft spacing is being used. This results in a water to water spacing of 620 ft or approximately 8.9 acres per five spot and does not require the drilling of any new wells.

Kentucky. Water flooding in Kentucky is confined principally to the western part of the state. Although some pilot floods are in operation in eastern Kentucky, no data have been released on them to date.

The initial project in the western Kentucky area was begun in 1941. At the present time it is estimated that approximately 1500 acres are under water flood. This includes patttern and flank, or peripheral floods, as well as some floods that are not listed in Table 4 due to inability of the authors to secure the necessary information.

Ohio. Water flooding was commenced in Ohio in 1939, shortly after water flooding was legalized in the state, by the drilling of 9 water intake wells and 4 producing wells to the Berea sand in the Chatham pool, Medina County, Ohio. Since that time the pool has been progressively developed until at the present time there are 800 acres being flooded.

The unusually erratic occurrence of the Berea sand, wide range of permeabilities and great variation in satura-

*Sohio Petroleum Company, Centralia, Illinois.
**Sohio Petroleum Company, Owensboro, Kentucky.
†Presented at the spring meeting of the eastern district API Division of Production, Hotel Cleveland, Cleveland, Ohio, April 26, 27, 28, 1950.

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Straight-from-the-shoulder-facts every oilman should know about

DRILL COLLARS

A Drill Collar is one of the most deceptive of all drilling tools. It looks so simple—just a hollow bar of steel. But a *good* Drill Collar contains more "hidden" qualities . . . more years of "know how". . . more testing, checking and *re*checking than probably any other drilling tool—*certainly far more than most oil men realize!*

Because of its apparent simplicity, many rule-of-thumb methods of judging Drill Collars have sprung up over the years—misunderstandings that cost the industry thousands of dollars in unnecessary losses every year. In a sincere effort to clear up some of these inaccuracies, Baash-Ross Tool Company—one of the largest and most experienced producers of quality Drill Collars—herewith summarizes some of the most important facts *every* oil man should know about Drill Collars . . .

First in selecting the steel to be used in a Drill Collar, chemical specifications alone are not enough!

For example, simply to specify that a Drill Collar should be made of 4142 alloy steel—or any other AISI specification steel—permits far too great a variance of alloys to obtain uniformity of the required physical properties in the finished product.

Alloys that produce uniform properties when used in small cross-sections produce entirely different sub-surface properties when used in a thick-walled product such as a Drill Collar. Therefore, the steel used in Drill Collars should be selected by the "hardening characteristics" as well as by chemical specification.

Baash-Ross does this by checking the "End Quench Hardenability" index of each individual heat of specified steel to determine exact hardening characteristics. Then, based on this test, each heat of steel is separately classified as to the size of product cross section that particular steel is to be made into to secure the desired uniform physical properties in the finished product.

Thus, by preselecting the steel for each Drill Collar by its individual hardenability characteristics—not by generalized chemical specifications—Baash-Ross assures each Drill Collar having the correct sub-surface as well as surface properties in the steel.

Second specifying that the Drill Collar is to be of press forged steel is not enough!

Although forged steel is denser than rolled steel, the really important thing is how the forging is processed—the way it is heat-treated to develop the forging to its best physical properties.

Through years of experience, Baash-Ross has learned that these processing steps are quite critical and must be accurately controlled to produce a Drill Collar free of structural defects and residual stresses. First, the forged bar is normalized and tempered over its entire length in one operation to produce a homogeneous structure and stress-free physical properties.

After the bar has been machined to the specified outside and inside dimensions, each end of the Drill Collar is again treated by an oil quench and tempering operations to produce the required uniform physical properties necessary for the threaded end zones.

Thus, a forged Drill Collar is produced that is free from residual stress to assure sustained straightness—with high impact values to resist shock loading—and with the end zones of such uniform physical qualities as to permit repeated recutting of the threaded ends without reduction of original joint strength!

Third specifying the size and type of joint desired on the Drill Collar is not enough!

Almost any machine shop can cut joints that will reflect proper gage standoff and will thread together, but the important thing is whether the joint is machined to obtain its full designed efficiency. Joints that are not produced with accurate thread form, lead and taper will permit wobble and cause failure. Furthermore, joint alignment in Drill Collars is particularly important because the rigidity of these members concentrates misalignment stresses on the pin portions and is the most common cause of joint failure in Drill Collars.

Baash-Ross assures accurate thread form, lead and taper in every joint by a prescribed method of checking and gaging that goes far beyond standard gaging standoff tests. Then the alignment of every joint is precisely checked with a Baash-Ross Alignoscope* to assure its not varying by more than 1/10 of 1% of theoretically perfect with respect to the longitudinal axis of the Drill Collar—virtually perfect alignment!

**For descriptive details see page 463 of your 1950 Baash-Ross Composite Catalog.*

These, too, are important specification features!

Although the above data outlines some of the principal points to look for in Drill Collars, these are vitally important, too . . .

▸ **STRAIGHT, CONCENTRIC BORE:** All Baash-Ross Drill Collars are held to wall-thickness specifications so rigid that, for a 2¼" bore or larger, the wall must not vary more than 1/16 *inch* for each 10 *feet* of product length—and the bores must be free from shoulders and other irregularities.

▸ **STRAIGHTNESS:** Each Baash-Ross Drill Collar is produced to *within ⅛ inch of absolute true at any point over its entire length!*

For additional important data on the many rigid specifications to which Baash-Ross Drill Collars are held, see pages 407 and 408 of your 1950 Composite Catalog. Or write direct for complete details.

Protect yourself and your well by insisting that every Drill Collar you buy meets the specifications outlined above. They represent the most dependable method we know of securing a uniformly good Drill Collar!

TABLE I

WATERFLOODS IN EDGAR, CLARK, COLES, CRAWFORD, CUMBERLAND, LAWRENCE AND WABASH COUNTIES, ILLINOIS

PRIMARY DATA

Flood No.	Pool Name	Operator	Producing Formation	Discovery Date	Depth Feet	Sand Thickness Feet	Developed Acreage	Recovery (Bbls.)	Recovery (Bbls.-Acre)	Average Initial Prod. (Bbls.-Day)	Type Structure	Original BHP. (PSI)	Oil Gravity (° API)	Oil Viscosity (cp)	Natural Water Drive
1	Bellair	Forest	500' Sand	1908	500	42	200				Dome		30.0		No
2	Bellair	Pure	500' Sand	1908	500	22	443	2,000,000			Stratigraphic	200	32.0		No
3	Bridgeport	Ohio	Bridgeport	1906	900	50							32.0		No
4	Browns East	Magnolia	Cypress	1946	2600	12	174	49,125			Stratigraphic		36.0		No
5	Casey	Forest	Casey		450	27					Dome		30.0		No
6	Calvin North	Magnolia	Biehl	1943	1800	15	10	34,000			Lense		32.0		No
7	Friendsville North	Magnolia	Biehl	1946	1500	15	40	12,933			Stratigraphic		35.0		No
8	Johnson North	W.L.Pickens	Casey	1906	450	15	300			75	Lense		32.0	18.0	No
9	Johnson South	Forest	Upper Partlow		475	55					Dome		30.0		No
10	Main	Tidewater	Robinson		900	22	110		8,000		Lense		35.0		No
11	Robinson	Ohio	Robinson	1905	900	20							34.0		No
12	Robinson	Ohio	Robinson	1905	900	20							34.0		No
13	Siggins	Forest	1st Siggins	1906	400	38	3000		3,600		Dome		32.0		No
14	Siggins	Pure	1st Siggins	1906	500	25	402	(2,000,000			Stratigraphic	200	35.5		No
			2nd Siggins	1906	500	6	269								

WATER FLOOD DATA

Flood No.	Date Started	Water Flood Acreage	Ave. Sand Thickness Feet	Average Porosity (%)	Ave. Perm. (md)	Oil Saturation (%)	Water Saturation (%)	Flood Pattern	No. of Wells Intake	No. of Wells Oil	Est. W.F. Recovery (Bbls)	Method of Production	Flood Water Type	Flood Water Source	Flood Water Treatment	Cumulative Injected Water 2-1-50 (Bbls)	W.F. Recovery 2-1-50 (Bbls)
1	1948	200	42	16.9	106	34.4		440', 5-spot	56	60	800,000	Flow	Fresh	Glacial Drift	Yes	3,100,000	
2	1948	443	22	18.6	149	36.0	44.0	440', 5-spot	131	125	1,400,000	Flow	Fresh	Gravel Beds	Yes	4,219,630	
3	1948	114	50					660', 5-spot	9	29		Pump	Fresh	Shallow Wells	Yes	518,200	
4	1947	168	12	18.0	100			Line Drive	3	12		Pump	Brine	Tar Springs	No	252,986	
5	1950	22	27	16.1	122	25.7		440', 5-spot	13	5	44,000	Pump	Fresh	Glacial Drift	No		
6	1947	10	15	19.0	85			660', 5-spot	1	4		Pump	Fresh	Penn. Sand	No	96,053	
7	1947	18	15	16.0	81			660', 5-spot	2	3		Pump	Fresh	Penn. Sand	No	109,843	
8	1949	50-60	15	19.0	200	45.0	25.0	5-spot Irregular	18	17		Pump	Fresh	Gravel Beds	No	600,000	20,000
9	1950	60	55	16.4	285	31.2		440', 5-spot	24	14	150,000	Pump	Fresh	Glacial Drift	Yes	1,292,000	50,000
10	1948	30-35	22	22.0	175	45.0	14.0	440', 5-spot	9	9	140,000	Pump	Brine	Basal Penn.	No	370,000	
11	1948	89	20					440', 5-spot	24	30		Pump	Fresh	Gravel Beds	No	278,000	
12	1948	113	20					440', 5-spot	25	37		Pump	Fresh	Gravel Beds	No	868,000	
13	1942	1300	38	16.7	42	32.0		440', 5-spot	322	251	4,875,000	Pump	Fresh	Glacial Drift	No	14,895,000	
14	1946	402	25	18.5	45	29.8	52.2	440', 5-spot	(125	(123		Pump	Fresh	Gravel Beds	Yes	(4,197,796	
	1946	269	6	18.3	66	26.7	52.5	440', 5-spot	(	(	(1,600,000	Pump	Fresh	Gravel Beds	Yes	(	

TABLE II

WATERFLOODS IN CLAY, EDWARDS, EFFINGHAM, GALLATIN, HAMILTON, JASPER, RICHLAND, WAYNE AND WHITE COUNTIES, ILLINOIS

PRIMARY DATA

Flood No.	Pool Name	Operator	Producing Formation	Discovery Date	Depth Feet	Sand Thickness Feet	Developed Acreage	Recovery (Bbls)	Recovery (Bbls.-Acre)	Average Initial Production (Bbls.-Day)	Type Structure	Original BHP (PSI)	Oil Gravity (° API)	Viscosity (cp)	Natural Water Drive
1				1944	1900	13	350				Stratigraphic	800	34.0	7.9	No
2	Albion South	Superior	Bridgeport	1944	1900	20	192	390,000	2,031		Lense	750	35.0		Yes
3	Alden	Texas	Aux Vases, McClosky	1938		13	1040								No
4	Blairsville	Texas	Aux Vases, McClosky	1942		20	640								No
5	Clans District	Pure	McClosky												
6	Clay City Dist.	Pure	McClosky												
7	Noble	Pure	McClosky												
8	New Harmony	Sun	McClosky	1939	2900	7	40	81,000	2,025		Porosity Trap		37.0		No
9	New Harmony	Sun	McClosky	1940	2900	5	100	330,000	3,300		Porosity Trap		36.0		No
10	New Harmony	Sun	Bethel	1940	2750	25	275				Blanket Sand		38.0		No
11	New Harmony	Superior	Waltersburg	1939	2220	40	490	6,800,000	13,878		Lense	975	36.0		Yes
12	Olney East	Texas													
13	Ste. Marie	Texas													
14	West Grayville	S.C.Yingling	Biehl	1948	1900	17	172	171,600	1,000	100	Stratigraphic	800	38.0		No
15	Maunie South	Magnolia	Tar Springs	1941	2200	16	280	484,000			Stratigraphic		37.0		No

WATER FLOOD DATA

Flood No.	Date Started	Water Flood Acreage	Ave. Sand Thickness Feet	Average Porosity (%)	Ave. Perm. (md)	Oil Saturation (%)	Water Saturation (%)	Flood Pattern	No. of Wells Intake	No. of Wells Oil	Est W.F. Recovery (Bbls.)	Method of Production	Flood Water Type	Flood Water Source	Flood Water Treatment	Cumulative Injected Water 2-1-50 (Bbls)	W.F. Recovery 2-1-50 (Bbls)
1	1946	350	13	20.0	325		29.0	Peripheral	3	18		Pump	Brine	Hardinsburg	No	520,000	
2	1946	192	20	19.7	304	22.0	29.0	Spot	3	30	106,400	Pump	Brine	Bridgeport	No		85,000
3			13					Peripheral	3	21		Pump	Brine	Penn Sand	No		
4			20					Peripheral	2	21		Pump	Brine	Penn Sand	No	253,000	
5	1945							Dump				Pump	Brine				
6	1944							Dump				Pump	Brine				
7	1944							Dump				Pump	Brine				
8	1948	40	7					Spot	1	1	10,000	Pump	Fresh	Gravel Bed	No	25,000	2,700
9	1949	60	5					Spot	2	3	50,000	Pump	Fresh	Gravel Bed	No	270,000	15,000
10	1949		23	17.0	20	25.0	30.0	20-Acre, 5-spot	2	4		Pump	Fresh	Gravel Bed	No	250,000	
11	1946	490	40	20.0	516	24.0	25.0	Line Drive	3	43		Pump	Brine	Waltersburg	No	1,900,000	170,000
12	Proposed																
13								Dump									
14	1949	172	17	20.2	265	22.4	23.6	Flank Injection	2	9	1,326,000	Pump	Brine	600' Water Sand	No	139,000	26,742
15	1947	180	16	18.0	500			20-acre, 5-spot	13	14		Pump	Fresh	Penn. Sand	No	1,248,383	

TABLE III

WATERFLOODS IN BOND, CLINTON, FAYETTE, FRANKLIN, JEFFERSON, MADISON, MARION, PERRY AND ST. CLAIR COUNTIES, ILLINOIS

PRIMARY DATA

Flood No.	Pool Name	Operator	Producing Formation	Discovery Date	Depth Feet	Sand Thickness Feet	Developed Acreage	Recovery (Bbls.)	Recovery (Bbls.-Acre	Average Initial Production (Bbls.-Day)	Type Structure	Original BHP (PSI)	Oil Gravity (° API)	Viscosity (cp)	Natural Water Drive
1	Benton	Shell	Tar Springs	1941	2100	35	2200	20,200,000	9180	350	Anticline	850	38.0	3.5	No
2	Boyd	Superior	Bethel	1944	2050	17	673	1,800,000	2675		Lense	700	36.0		Yes
3	Centralia		Benoist	1937	1400										
4	Odin	Ashland	Cypress	1945	1700	11	354	380,736	1076	90	Dome	700	37.0	8.3	No
5	Patoka	Sohio	Benoist	1937	1410	27	565	2,800,000	4952	80	Anticline	550	39.0	5.6	Partial
6	Patoka	Sohio	Rosiclare	1937	1550	9	469	153,000	326	100	Anticline	600	40.0	4.1	Yes
7	Salem	Texas													

WATER FLOOD DATA

Flood No.	Date Started	Water Flood Acreage	Ave. Sand Thickness Feet	Average Porosity (%)	Ave. Perm. (md)	Oil Saturation (%)	Water Saturation (%)	Flood Pattern	No. of Wells Intake	No. of Wells Oil	Est. W.F. Recovery (Bbls)	Method of Production	Flood Water Type	Flood Water Source	Flood Water Treatment	Cumulative Injected Water 2-1-50 (Bbls)	W.F. Recovery 2-1-50 (Bbls)
1	1949	1900	37	19.0	65			20-acre. 5-spot	84	120		Pump	Fresh	Lake	Yes	1,600,000	
2	1945	673	17	18.0	150	20.0	24.0	Line Drive	3	58		Pump	Brine	Bethel	Yes	2,380,000	
3	Proposed																
4	1949	136	15	20.0	78	66.0	33.0	Peripheral	10	20	985,000	Pump	Brine	Tar Springs	No	26,000	
5	1943	527	27	19.0	110	53.0	20.0	660', 5-spot	62	81	6,400,000	Pump	Brine	Tar Springs	Yes	16,300,000	5,451,000
6	1948	469	9	18.8	223	65.0	30.0	Peripheral	14	12	1,500,000	Pump	Brine	Tar Springs	Yes	454,300	219,000
7	Proposed																

—another reason

for Totco on your rig

RELIABILITY

1950
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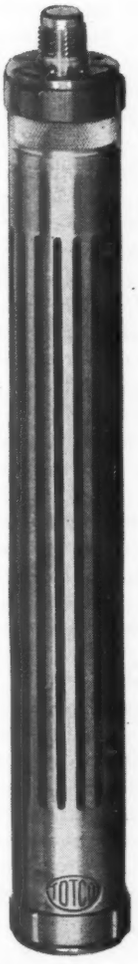

With a TOTCO Recorder you have *simplicity* of operation, *sustained* accuracy in recording, and *durability.* Twenty years on rigs back up TOTCO reliability . . . just a few TOTCO-equipped rigs in 1930, a whale of a majority today.

A major oil company wrote, "99% of our TOTCO runs have been *okay to be logged.*" That kind of reliability is possible because TOTCO is the most dependable, precision-built instrument in the oil fields—no expense has been spared in its manufacture.

Whenever and wherever you need a drift indicator, TOTCO field representatives can be relied upon to get you what you need when you want it. You can depend on TOTCO instruments and on TOTCO men—they'll both serve you well.

Be **SURE** *you know, use* **TOTCO**

YOU CAN TAKE TOTCO READINGS ANYTIME

Run in and out on measuring line.

Dropped down drill pipe; picked up with core barrel overshot.

Dropped down drill pipe; recovered when bit is changed.

Run in the Recorder connected to a core barrel overshot when picking up a retractable core barrel.

Run in and out on ordinary sand line.

TOTCO
Recorder

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Export—Lucey Export Corporation, New York City

TABLE IV

ACTIVE WATER FLOOD PROJECTS IN INDIANA, KENTUCKY, OHIO & WEST VIRGINIA

PRIMARY DATA

Flood No	Pool Name	County & State	Operator	Producing Formation	Depth Feet	Sand Thickness Feet	Developed Acreage	Recovery (Bbls)	Recovery (Bbls/Acre)	Type Structure	No. Wells Drilled	Oil Viscosity (cp)	Average Initial Production (Bbls-Day)
1	Birk City	Daviess & Henderson, Ky.	Several	McClosky Lime	1875	14	386	1,464,000	3,800	Monoclinal Nose	39		350
2	Cane Run	Daviess, Ky.	Cumberland & Kenrow	Waltersburg	625	20	25	55,800	2,230		14		
3	Cane Run	Daviess, Ky.	Ellis et al	Waltersburg	625	20	20	34,800	1,740		8		
4	Corydon	Henderson, Ky.	Sun Oil Co.	McClosky Lime	2600	6	86	234,500	2,780	Porosity Trap	5		172
5	Dundee	Ohio, Ky.	Sohio Pet. Co.	Cypress	525	14	135	198,500	1,470		55	10	40
6	Friendship	Ohio, Ky.	Sohio Pet. Co.	Hardinsburg	525	19	18	48,000	2,670	Stratigraphic Trap	12	13	20
7	Haynesville	Ohio, Ky.	Cumberland & Kenrow	Tar Springs	375	18	53	233,900	4,410		31		
8	Uniontown	Union, Ky.	Sun Oil Co.	Waltersburg	1800	25	180	450,000	2,500		18	5	121
9	Weller	Ohio, Ky.	Felmont Oil Co.	Tar Springs	685	25	450	2,700,000	6,000	Stratigraphic Trap	170	8	
10	Weller	Ohio, Ky.	Sohio Pet. Co.	Tar Springs	685	28	193	1,247,600	6,480	Stratigraphic Trap	79	8	100
11	Dodds Bridge	Sullivan, Ind.	Ohio Oil Co.	Pennsylvanian	850	30							
12	Heusler	Posey, Ind.	Sun Oil Co.	Waltersburg	1750	10	175	438,000	2,500	Stratigraphic Trap			
13	Chatham	Medina, Ohio	Preston Oil Co.	Berea	430	75	135	131,000	970	Monoclinal			
14	Chatham	Medina, Ohio	Dymo Oil Corp.	Berea	375	43	440	1,485,000	3,380	Monoclinal	73	10	
15	Chatham	Medina, Ohio	Conklin & Whitman	Berea	400		180			Monoclinal			
16	Chatham	Medina, Ohio	Belmont Quadrangle	Berea	400		117	232,100	1,990	Monoclinal			
17	Cabin Creek	Kanawha & Boone, West Virginia	Pure Oil Co.	Berea	3000	13	2700	10,621,800	3,940	Monoclinal		2	60
18	Cabin Creek	Kanawha & Boone, West Virginia	Preston Oil Co.	Berea	3000	14	420	1,332,500	3,170	Monoclinal			
19	Jeffries	Posey, Indiana	Magnolia	Clore		11	120	44,913		Stratigraphic			

WATER FLOOD DATA

Flood No.	Date Started	Water Flood Acreage	Ave. Sand Thickness Feet	Average Porosity (%)	Ave. Perm. (md)	Oil Saturation (%)	Water Saturation (%)	Flood Pattern	No. of Wells Intake	No. of Wells Oil	Method of Production	Flood Water Type	Flood Water Source	Flood Water Treatment	Cumulative Injected Water (Bbls)	Est. W.F. Recovery (Bbls)	W.F. Recovery 1-1-50 (Bbls)	Injected Water to Produced Oil Ratio
1	1945	386	14	13	350			Peripheral	4	24	Pump	Brine	Wells	None	1,500,000	425,000	303,000	5.0
2	1941	29	20	21	65	42	31	5-spot	15	11	Pump	Fresh	Well	Yes	1,701,000		108,000	15.8
3	1945	18	20	21	41	43	31	5-spot	11	9	Pump	Fresh	Well	Yes	545,000		84,000	6.5
4	1947	33	6					Flank	1	3	Pump	Brine	Well	None	135,100	24,000	13,200	10.2
5	1950	50	14	17	100	50	20	5-spot	10	13	Pump	Fresh	Well	None	0	150,000	0	
6	1948	10	19					Irregular	2	4	Pump	Brine	Well	None	43,000		3,600	11.9
7	1945	39	18	20	61	57	15	5-spot	18	28	Flow	Fresh	Surface	Yes	895,500		129,000	6.9
8	1947		25	18	56		30	Flank	2	15	Pump	Brine	Produced	Yes	193,200		9,100	21.2
9	1949	311	25	20	100	50	25	5-spot	68	80	Pump	Fresh	River	Yes	1,213,000	1,240,000	0	
10	1949	175	25	20	100	50	25	5-spot	28	40	Pump	Fresh	River	Yes	232,000	690,000	0	
11	1949	75	30					5-spot	11	19	Pump	Brine	Well	None	200,000		0	
12	1946	70	10	19	282		30	Flank	2	8	Pump	Brine	Produced	Yes	202,000		62,000	3.3
13	1944	52	75	17	75	35	38	5-spot	47	44	Pump	Fresh	Surface	Yes	4,790,000		215,000	22.3
14	1939	440	43	17	75	35		5-spot	107	222	Pump	Fresh	Well	Yes			1,330,000	
15		180						5-spot	71	98	Pump	Fresh		Yes				
16	1941	117						5-spot	74	62	Pump	Fresh		Yes	8,412,000		378,300	22.2
17	1937		13	15	60	42	20	7-spot	86	45	Pump	Fresh	Surface	Yes	11,000,000		425,000	25.9
18	1948	73	14					7-spot	9	7	Pump	Fresh	Surface	Yes	367,700		21,900	16.7
19	1948	75	11	18.6	203			5-spot	4	12	Pump	Fresh	Penn. Sand	No	236,033			

tions result in a wide range of input volumes. Due to these erratic conditions it is necessary to inject and produce large volumes of water to obtain the water flood oil production.

West Virginia. In 1937 water injection was begun in three wells in the Cabin Creek field, West Virginia. Since then development has been slow but at the present time water is being injected into 95 wells in the field by two different operators. This area is unusual in that the 7-spot pattern is being used. This was due to the original drilling pattern of the field and also because it was considered economically necessary to use old wells.

Summary

For the most part the area being considered is comprised of stripper or marginal leases. As a result of the poor condition of the surface and subsurface equipment, much of which has been in use for 20-30 years, it is necessary to re-drill a large percentage of the properties. The poor condition of the well equipment also brings more complications insofar as plugging of off pattern wells is concerned.

In many areas vacuum and/or gas or air repressuring has been previously practiced. This has resulted in depleted zones of high permeability in many cases that give considerable difficulty during the flooding operations.

The problem of an adequate water supply varies widely. For the most part, the areas being flooded have been blessed with a good local water supply. This is not true in western Kentucky where most of the water sands are lenticular and of small areal extent. Rivers offer a possible source of water supply but a supply that requires large expenditures for lines and plants.

The active water flood projects in the area vary from 300 to 3000 ft in depth. The cumulative injected water to produced oil ratio varies from 3-26 to 1.

The only limestone reservoir flood that has recovered any appreciable amount of oil is the Birk City project in Daviess and Henderson Counties, Kentucky. A total of 303,000 bbl of water flood oil has been recovered from 386 acres. This amounts to about 800 bbl per acre. It is estimated that the ultimate recovery will be 1100 bbl per acre.

Sufficient information was available on only 6 projects to compare primary recovery and water flood recovery on planned pattern water flood projects. On those the primary recovery amounted to 2750 bbl per acre while the water flood oil recovered to January 1, 1950 has amounted to 3230 bbl per acre, with some additional water flood oil yet to be recovered.

To the writer's knowledge only one cooperative and one unitized project is now in operation in the area. Two or three additional cooperative programs are in the planning stage in western Kentucky and these will probably follow the general trend previously used in the Illinois basin.

It is estimated that at least 3000 acres are now under water flood in the states of Indiana, Kentucky, Ohio, and West Virginia. Of this amount at least 900 acres have been developed during the past two years. These developments are being watched with interest by operators in the area and future developments may be greatly influenced by the performance of these floods.

May Save 14 Billion Barrels of Oil

Old oil wells, once thought to have yielded their last recoverable drop of crude petroleum, are being reactivated as a result of oil industry technical advancements to produce from 25 per cent to 300 per cent of their original recovered petroleum. By flooding the old wells with water under pressure it is estimated that up to 14 billion barrels of additional crude oil can be obtained from now-abandoned sites. Other recovery methods being used by the industry are vacuum pressure, air and gas injection. Measures like these are indicative of the oil industry's constant efforts to get the most out of the nation's natural resources.

Acknowledgment

The authors express their appreciation to the many individuals and companies who made available the data for presentation.

Rig to Office Communications*

C. J. PAINE† AND JERRY STOVER‡

THE question most often asked me regarding radio communication for the drilling industry is: "What does radio save you?"

That is a hard one to answer, and from the standpoint of dollars, probably an impossible question to answer with any great accuracy.

We do know that our mileage has dropped off on our field cars and our trucks are getting a job done quicker and with less travel. We know that our telephone bills are less, but all of you know that with the varying activity in different localities that a drilling firm encounters, that trying to put the finger on actual savings is a hard task.

We have a few accurate checks. By applying a sort of flexible formula to our daywork billings to customers, we find that they are about 30 per cent less than they were before we began using radio. That has a double-bitted advantage. We have never been able to charge a rate for daywork, because of competitive conditions, that would allow us to break even. Therefore, the more daywork we billed, the greater the loss. On the other side of the fence, the producer was spending his dollars on daywork beyond what he now spends. With radio, both the producer and contractor are saving. How does this saving occur? In the area where we work there are several sands and limes capable of producing oil. From location to location these sands vary, to the extent that almost all of the wells drilled in the area are wildcats. Under the old system, when a sand was encountered the rig was immediately shut down until a representative of the company could be contacted. This sometimes took several hours. Now the wait is usually less than 15 min. When a driller gets a change in drilling time he will immediately contact the geologist or engineer in the area by radio, give him the dope, and then follow instructions by radio from then on even while the company man is on his way to the location in his car. The same plan works on wildcats. Instead of the company having an engineer, or two of them, on the location sweating it out 24 hr a day, one man can easily and efficiently check two or three wells in an area.

One incident I remember happening a year or so ago would have been utterly impossible before radio. We were operating four rigs for one company in North Texas, and on this hectic day we were down to one company representative, a hard working, smart young engineer. Seems that vacations and sickness had put the rest of the company men out of combat for the day. One rig was near Jacksboro, one near Olney and two in the far western part of Young County. One rig was drilling in, another taking a drillstem test, one coring, and the other running a Schlumberger. Normally, this would have taken an engineer with a jet propelled fighter of at least seven league boots. But not with rig to rig radio. Parking himself in the doghouse of the rig near Jacksboro, the engineer virtually kept himself at all of the locations at once. The operations were all a success and were just as successful as they would have been had a company man been on each location. I don't necessarily recomend this procedure as a constant diet, but when the occasion arises, the job can be done and done well by radio.

Therefore, we can accurately say that radio communication in the drilling industry saves dollars for the contractor and the customer by the reduction in shutdown time waiting for orders.

Probably the greatest saving is in reduced shutdown time for breakdowns and repairs. Early in our company's radio life, I was driving between Wichita Falls and Dallas late one night. Naturally, I had my radio on. I heard a driller on a rig call one of the pushers at his home and report that a bearing on the pump shaft was heating and seemed about ready to go out. The pusher told the driller to watch the bearing, shut down if it seemed to be going out. He then called our mechanic who happened to be within radio range in his pickup, discussed the trouble with him and asked him to go by the rig on his way into town. The mechanic picked up the bearing, went to the rig, replaced it that night and the shutdown time was practically nil. Had it not been for radio, the driller would have either shut down until morning or have run the rig until the bearing failed, which would have meant a lot of down time either way. There are many stories I could tell you about what radio has meant to us on repair jobs. Needless to say, our shutdown time waiting for repairs has practically become nonexistent.

Radio has made another direct contribution to efficiency. In years past most pushers felt that to get a good job done they must stay on the job most of the time, day and night. There was always that constant fear in their minds that if they left something would happen. And lots of times it did, just as they drove around the corner, with the result that a rig might be shut down for several hours. This kind of thing didn't exactly contribute to good sleep and peace of mind and sometimes a pusher would be so worn out from lack of sleep that he didn't deliver his best in the clutches. Radio has helped eliminate this to a great extent. As we have radio stations in all pushers' houses, a man can now go home at a reasonable hour and go to sleep knowing that if anything out of the ordinary happens he will know it within a few moments. Many times this means a trip back to the rig with supplies, more often it means that the problem can be discussed with the driller and the solution be worked out without the pusher leaving his bedroom. At all times it means that a pusher can go to sleep without worry.

A lot of contractors have told me they would never put radios on rigs because they were afraid that pushers would do all their pushing from the local pool hall or the hotel lobbies. That is one fear that can be eliminated, and eliminated completely, according to our experience. Our men are getting a better job done with radio than they did before and if anything they are spending more time on the rigs now than they did before radio.

Here is one byproduct of radio that does not put any money in the bank but it surely is a source of satisfaction. I can remember back over the years that I would start straining my eyes from the minute I could see a rig, trying to see what was going on. If the kelly was up in the derrick, or a stand

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of pipe was out when I thought it should not have been, or if I could see smoke over the hills where the rig should have been, my mind started working up all kinds of dire things that must be wrong. I have probably dreamed more fishing jobs two miles from a rig than anyone in the drilling business. Now you don't wonder when you drive up. If anything is wrong, you would know it a long time before you could see the rig. If you are especially curious, pick up the mike and ask the driller.

I wonder how many miles all of us have wasted in our life trying to find someone in the field. Many times I have tailed someone all over a county, rig to rig, until I figured the guy had probably blown away. Now when we want someone in our outfit we just pick up the mike and tell him where to be.

Truck dispatching has really paid off. There are fewer empty return trips with radio equipped trucks, and when something is needed in a hurry a truck can always be found and usually that truck will be near enough to what you want that a lot of time is saved. This also means less shutdown time for the rigs.

In talking to various contractors about radio communication, I find that a lot of field men don't want it. This is true in many cases and it is hard to figure out why this attitude exists. I have also talked to a lot of contractors who now have radio equipment and everyone of them tells me that their field men are completely sold and they usually are after management to add additional equipment.

My best example of how our field men feel about radio happened just a few days ago. I had told them that we would have to be without our equipment for two days while it was being changed over to a newly assigned frequency. Their question to me was "But how are we going to run the rigs without radio?" And they were serious.

I think most of the opposition from field men who have not looked into radio comes from the fact that they think they are going to be burdened with a lot of knobs and gadgets and tubes that will constanty be getting out of order. Nothing could be further from the truth. Jerry Stover, who knows almost everything there is to know about oil field radio, both from the practical and the technical standpoint, will tell you a lot about how simple and trouble-free radio really is. Just a word about Jerry. He installed our equipment as his first oil field job about three years ago and since that job was the first radio installation in the contract drilling industry, he was

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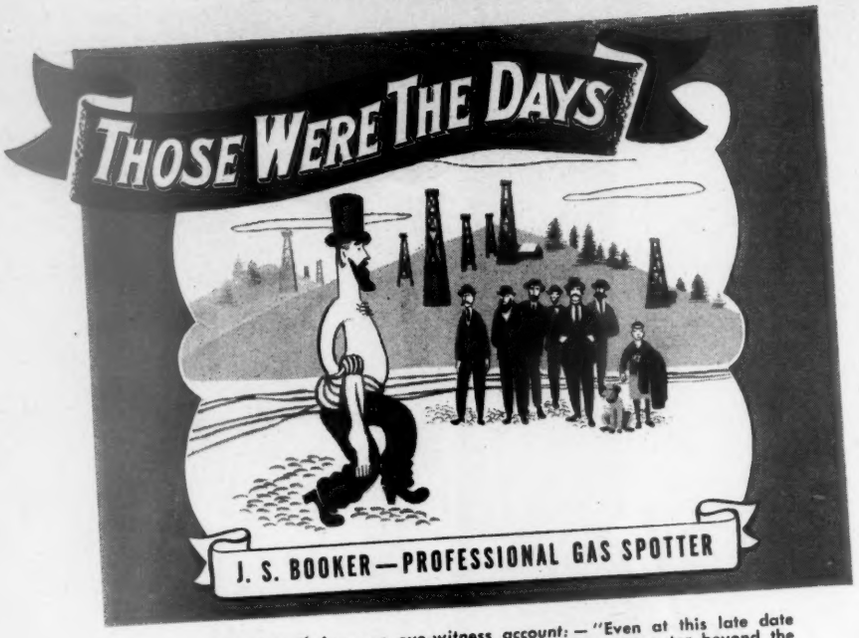

Condensed from an eye-witness account: — "Even at this late date (1865) there is little to guide the adventurous operator beyond the conceded existence of oil veins in the inferior rocks. A new profession of men, claiming to be gifted with extraordinary powers, has arisen in oildom — namely 'oil smellers' and 'gas spotters.' J. S. Booker, an Ohio man, claims to be able to spot gas. His particular virtue lies in the muscles at the back of his neck, which rise up and irritate him in the presence of natural gas. Booker's own story is that an attack of asthma left him in a sensitive state, so that when he passes over a vein of gas the electricity runs through his legs, up his spine, and knots the muscles of the neck. The practical people of oildom reason this way: 'If there be anything to gas-spotting, we may as well avail ourselves of it as not, for the diviner charges only from $25.00 to $100.00 for his services, and this is an inconsiderable item in the general expense, see we mean to bore anyhow'."

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in on the ground floor of this business with all its problems. And he has been able to whip the problems as they arise.

About the only characteristic common to all drilling rig radio systems is that they use radio! There is no such thing as a "standard package." Although this is true of nearly every radio system, it is particularly true of drilling systems. Rigs are different, areas of operations are never the same and, most important, each drilling contractor has his own idea as to how he wants to use radio.

Fortunately, radio is an extremely flexible tool and can be adapted to almost any type of operation. To get the most out of any radio system, however, it must be properly engineered.

To do this, even with the assistance of a radio engineer, the contractor should know what the various elements of a system are, what they will do, what they won't do, and how much each costs.

Elements of A Two-Way System

A two-way radio system for drilling operations is usually a combination of three basic elements:

1. The mobile unit in cars and trucks.
2. The portable unit on drilling rigs.
3. The office station, which can be at a toolpusher's house or in an office.

Mobile Unit

The mobile unit consists of a transmitter and receiver that are usually mounted in the trunk of passenger cars and in tool boxes on trucks. The output of the transmitter is usually 30 to 60 watts. (It may be interesting to note that the output of some broadcast stations is 50,000 watts!) The antenna is a steel whip and spring. It can be mounted either on the roof or side of the vehicle. The standby battery drain of the mobile unit is only slightly greater than that of a normal car radio —about 9 amp. The heavy current drain is only during the transmitting time.

For this reason, heavy duty batteries and slow speed generators are required only if the car does a great deal of city driving where the normal generator does not turn up enough to build the batteries up.

The calls to a mobile unit are received over a small metal cased speaker. It is mounted up on the firewall and does not interfere with the normal car radio. The small control unit is mounted under the dash. Two types of microphones are available. The small military type mike is used in a large number of systems but the handset type is more popular in oil

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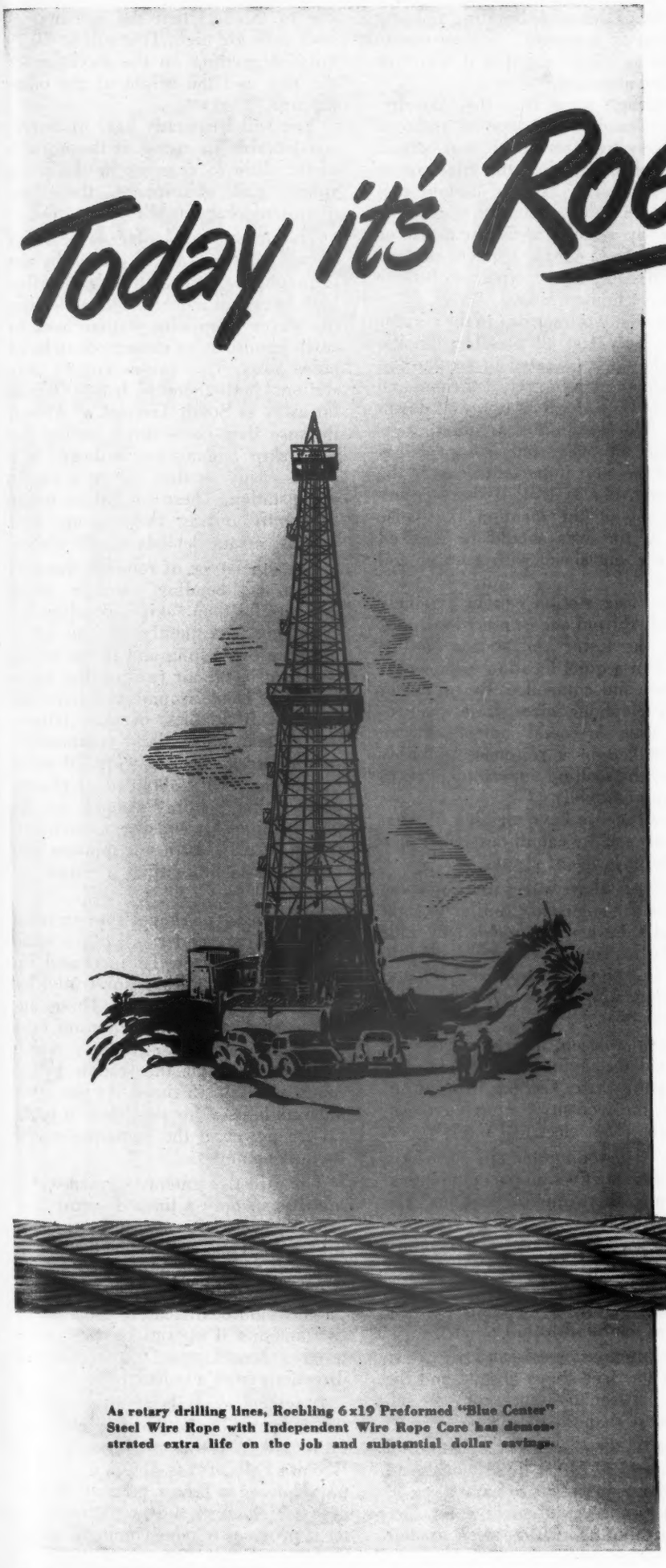

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field use because the receiver adds a great deal to the readability of a signal when the car is going fast or in a noisy location.

Rig Stations

The rig unit is usually a mobile unit mounted up in a portable steel cabinet with provisions for supplying power. Instead of the whip antenna of a mobile unit, however, a special coaxial antenna is mounted atop the derrick and connected to the radio by means of a small flexible cable.

The storage battery is mounted at the rear of the cabinet and kept charged by a generator mounted on one of the drilling engines. Steam rigs use a turbine-driven generator and those rigs where 110 volt power, either ac or dc, is continually available can use a converter or charger. Though the battery-generator combination is a little more trouble than a straight ac unit, it has the big advantage that while rigging up, or during an engine breakdown, the radio can be operated from the battery for a limited time. If the battery goes down, it is a simple matter to exchange it for a fresh one from a car or truck.

The radio cabinet is normally placed in the dog house beside the knowledge box. So that calls may be heard on the rig floor, a small weatherproof speaker is mounted near the drawworks. The driller can then hear if his rig is being called and step into the dog house to answer.

Office Station

Most drilling companies use a 50-watt office station. It is very similar in appearance and operation to the rig units. In fact, if good dependable 110 volt ac power is available it could be used on a rig.

Office stations with 250-watts output are frequently used. The extra power permits the station's signal to be received better in a location where the electrical noise level is high. For example, a mobile unit may be driving along a power line or the station on the rig may be receiving excessive interference from the light plant or magnetos. The higher powered office station does not necessarily increase the two way communications range because the "talk-back" power of the rig or car is still only fifty watts. There are methods of increasing the range in both directions, and these will be discussed later.

The antenna of an office station is usually placed on a tall tower in order to give it maximum range to cars and rigs. This tower may vary from a 40-50-ft pipe mast at a toolpusher's house to a 150 to 300 ft lattice steel tower.

One question is always asked, "Why can't I just put my station antenna on the roof of this office building and save the cost of a tower?" The answer to this is so important that it warrants detailed attention.

Although it is true that the frequency modulation type of radio is relatively free from static and certain forms of interference, the interference from diathermy, x-rays, certain motors, neon lighting, etc. can reduce the range, by as much as 50 per cent. For this reason, a station with its antenna located in the downtown area of a city will have limited range.

This is not too serious in the smaller towns, but, if at all possible, the station should be situated in a suburban or residential area even if the antenna will not be as high as it would downtown. The selection of a "quiet" location for the office station is probably one of the most important items in the planning of a system. If there is any doubt about the location the noise level of the area should be checked before going ahead with a tower and station.

The office station can be remotely controlled from one or more locations. Thus, the tower and station can be placed in a quiet location on the edge of town and controlled, by means of leased telephone wires, from a downtown office. A second control unit can be installed in a residence, possibly that of the drilling superintendent, to receive night calls.

Now that we have an idea of what the units are, we can discuss what they will do in terms of range.

The very short waves used by these systems are somewhat similar to light in that they can be shielded by hills and the horizon. Fortunately, they do bend to some degree, however, and communication is possible beyond actual line-of-sight.

For this reason, maximum range is obtained by having the antenna high and in the clear, keeping in mind, of course, the necessity for having a location free from electrical interference.

The intervening terrain will have considerable effect on the communication range between two stations. The range in hilly mountainous country is usually very limited unless advantage can be taken of the peaks. The ranges I will describe here are average for the rolling terrain common to most parts of the Southwest.

The antennas on cars and trucks are only a few feet above ground and the range between two such units is seldom more than 20-30 miles.

Because the antenna of a rig station is usually 120-140 ft high it can send and receive messages to cars 40 to 50 miles away. To another rig or an office station the range will be even greater due to the fact that the antennas at both ends are high. This will be 50-70 miles depending on the elevation of the rigs and the height of the office antenna.

You will frequently hear of ranges considerably in excess of those given above. Due to changes in the ionosphere and atmosphere, there are often temporary increases in range.

The most spectacular increase is known as "skip" and is caused by the ionosphere, several hundred miles high, acting as a mirror and reflecting the waves from your station back to earth hundreds, or even thousands, of miles away. This causes you to hear stations (and them to hear you) as far away as South America or Africa. Because they come down out of the sky, "skip" signals can be heard in a car as easily as they can at a rig or office station. These conditions occur frequently during the summer and during certain periods of the winter.

The other type of range increase is known as "bending" and is much more useful than "skip". Bending occurs most frequently in the early morning or evening and is due to the moisture in the air causing the radio waves to bend around and over the horizon. It doubles, or even triples, the normal ranges, and communication between rigs and cars 70 miles apart has been obtained. Unfortunately, this bending cannot be depended upon for consistent communication. It may last a few minutes and seldom lasts more than a couple of hours.

The consistent range from an office station to cars and rigs can, in some instances, however, be increased up to 70 and 100 miles, respectively, by using directive antennas. These antennas concentrate the radiation in a given direction and effectively multiply the power of the station by as much as 10 or 15 times. As the same antenna is used for receiving, it picks up the power of the incoming signal by a like amount.

The directive antenna provides this increase in only a limited sector and at the expense of range to the remaining areas. Thus such an antenna can be used only if the office is primarily to one side of the operation. For example, it would be difficult to use a directive antenna if operations were scattered a considerable distance in all directions from a central office.

A typical example of directive antenna operation is the one used by Fain and McGaha Oil Company at Wichita Falls, Texas. It is a 6 element unit, having a power gain of 10 db, 300 ft high. With a 50-watt transmitter it provides reliable communication

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Fig. D312—Spang Swivel Rope Socket. Figs. D330, D335—Spang Boxes and Pins. Fig. D360—Spang Straight Drilling Bit. Fig. D322—Spang Weldless Jar. Fig. D328—Spang Drilling Stem. Fig. D368—Spang Twisted Drilling Bit. Fig. D380—Spang Regular Bailer. Fig. F514—Spang Reversible Casing Ripper. Fig. F481—Spang Multi Slip Collar Socket. Fig. F476—Spang Solid Bored Friction Socket. Fig. F460—Spang Center Rope Spear. Fig. F467—Spang Three-Prong Grab. Fig. F482—Spang Full Circle Three Slip Slip Socket. There are many other types of Spang Fishing Tools, not illustrated.

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range, in its beam, or 85 miles to cars and 110 miles to rigs. The range off to the sides and back is only 35 miles to cars and 50 miles to rigs, however.

The best way to show you how these units are operated is to let you "listen in" on a few systems in operation. We took a wire recorder out into the field and recorded a few conversations as they went on over the petroleum radio channels. These are the routine day-to-day conversations and, while not as dramatic as some of those we often hear, they do serve to indicate the ease with which field personnel have adopted this new tool.

On July 1, of this year, the Federal Communications Commission issued new rules and regulations for the mobile radio service. These rules established a Petroleum Radio Service and provided for the assignment of 30 exclusive frequencies for the use of the petroleum industry.

Up until that time petroleum radio had only three shared frequencies on an experimental basis. These three channels quickly became overloaded. In 1947 the Central Radio Committee of the API made formal representation to the FCC for the establishment of a permanent Petroleum Radio Service with additional exclusive frequencies.

Even before these new frequencies were made available, the various petroleum radio users formed a co-ordinating committee for the purpose of allocating the frequencies within the industry. This will prevent the overcrowding of any one frequency in a particular area and thereby provide maximum utilization of all frequencies. This does not mean that a company can expect to have an exclusive frequency. There are still far too few frequencies to go around and the best that can be done is to spread the companies out as evenly as possible. The sharing of a frequency is not as bad as it first sounds. In fact, for the small radio user it has certain advantages. Authorization can be obtained from the FCC for companies sharing the same frequency to share common facilities, for example, there are several instances where two or more companies share one base station with each company having a remote control unit in its office. Also, in an emergency, the rigs or station of one company may relay messages for the cars or rigs of another company that are out of range of their own base station.

All radio stations must be licensed by the Federal Communications Commission. Upon proper application and showing of eligibility, the FCC will grant the license with the frequency and call letters. There is no cost for these permits and the small fellow with one rig and a car can obtain a license just as readily as a major oil company. Before filing for an FCC license it is necessary to obtain a frequency recommendation from the Petroleum Coordinating Committee.

The necessary FCC forms and assistance in their preparation can be obtained from the FCC district offices. Also, the various manufacturers' representatives selling radio equipment have them and are, of course, only too glad to help prepare them, without charge!

Due to the release of these new frequencies there has been a tremendous flood of applications and the FCC has a rather large backlog. In planning the installation of a system it is well to allow at least 6-8 weeks for the processing of the license application by FCC.

Costs

Good radio communication is not cheap, but by effective planning and study, the cost of a system can be kept within reasonable limits. The costs of the individual elements of a system will vary to some degree, depending on type of equipment and installation labor costs. The figures I shall give here, however, are average throughout the Southwest and are sufficiently representative to be used for budget purposes. These costs, of course, include all necessary labor and the various accessories.

The cost of a mobile station installed in a car or truck is about $600. The rig station, with its special accessories such as battery, cabinet, generator, rig antenna, etc. is about $950.

The cost of the office station varies considerably depending almost entirely on the antenna height required. The tower is usually the most expensive item. A 180-ft lighted tower costs $2200, erected. A 50-watt office station with such a tower will run about $3200.

Thus, a system consisting of four cars, five rigs, and an office station would cost a little over $10,000 installed.

All repairs or adjustments to the equipment must be done by an engineer with a FCC license. It is not necessary to have such a man on your payroll as maintenance service is available on a per-call or contract basis.

Contract maintenance that furnishes all labor, tubes, and parts for a flat monthly fee is usually more attractive because the user can set aside a fixed amount each year for his radio maintenance. The monthly rates on this basis, vary, of course, depending on the locality, but an average figure is $7.50 per car and $20 per rig or office.

It is unlikely that there will be any major reduction in equipment or operating costs in the foreseeable future. One reason for this is that as more and more users come on the air the FCC technical specifications must, of necessity, be increased to reduce interference. Thus, any advantage gained by quantity production will be offset by the increased cost of manufacturing and maintaining equipment to the more rigid specifications.

It would be nice if, along with the newer equipment, we could get greater ranges for petroleum operations. Such is not the case, however, because the range limitation is an inherent characteristic of the frequencies employed by the mobile service. This is demonstrated by the fact that the range of present day equipment is still only slightly greater than it was a few years ago. New types of vacuum tubes and circuit design have helped but the major improvements have been in developing equipment that will work on very close frequency separation without interference. As more and more users of mobile radio come on the air the demand for frequencies makes it necessary to assign them closer and closer together. Let us hope that the research laboratories can continue to keep ahead of this radio "squeeze" play. * * *

Urges California Conservation Law

Intensified and uncontrolled oil development and production programs commonly result in great waste of our irreplaceable natural resources, according to L. A. Cranson, president of Oil Producers Agency, in a talk before the American Association of Oilwell Drilling Contractors in Los Angeles May 22.

Cranson stated that it is significant that "all of the principal oil producing states with the exception of California and Wyoming have adopted statutes, which in large measure accomplish conservation objectives. In no instance has any such law been repealed, nor is it probable that any of these states would be without such legislation now that the benefits from it have become obvious. Fifteen states, with 77.7 per cent of national production in 1949, have conservation laws. California, with 18.1 per cent, and Wyoming, with 2.55 per cent, are the only two major oil-producing states without such legislation, and Wyoming is now considering such legislation."

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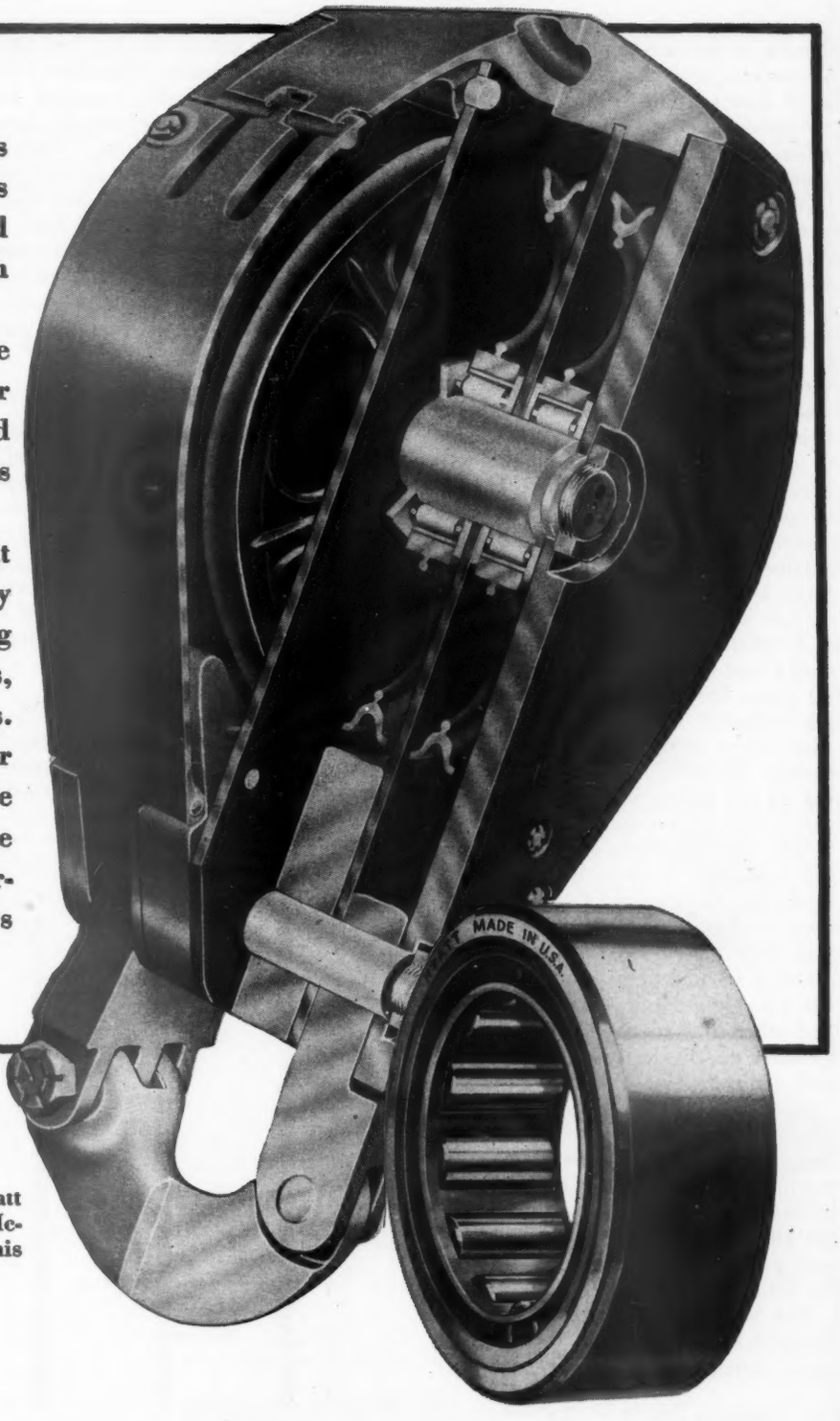


There are four of these husky Hyatt Roller Bearings on the sheaves of McKissick 200-ton traveling blocks as this partly cut-away view shows.

HYATT ROLLER BEARINGS

TIME FACTOR IN CEMENTING†

BRUCE BARKIS*

PRIOR to the development of the gun perforator, and its introduction on the Gulf Coast about 1935, casing was cemented above the productive sand. Obtaining an effective cement seal around the bottom end of a casing string for this type completion was not as difficult as attempting to exclude gas or salt water from a productive oil section several hundred or several thousand feet above the cementing depth.

As the gun-perforated type of completion developed, it was found necessary to squeeze cement through the primary perforations to exclude gas or salt water, which entered the well because of cementing failures. The art of squeeze cementing was improved through the development of cement retainers and removable cementing tools, and this practice is still used in certain areas.

Scratchers were introduced on the Gulf Coast in 1940 and during the past 10 years have been accepted by the oil industry for improving cement placement and the percentage of cement fill behind the casing. Centering of the casing is provided by the use of spring bow centralizers.

The transition from squeeze-cementing technique to improved primary cementing has brought about a general review of the entire cementing operation. This has resulted in the development of rig practices, improved blowout preventers and cementing heads and other time saving items that have speeded up this critical phase of oil well drilling.

This time study of the cementing operation was made to determine (a) the time required for each phase of the job, (b) whether any considerable saving in time might be made, and (c) the effect of delays, or stoppages of casing movement, on the success of the job.

The several phases of oil well cementing are reviewed in their operational sequence.

Laying Down Drill Pipe

It is customary on the Gulf Coast to lay the drill pipe down as the drilling string is pulled for the last time before running casing. One side of the casing rack is usually reserved for drill pipe. Various improvements have been made in the technique of breaking the individual joints and laying down the several hundred units comprising the drilling string. There is small room for improvement in this standard operation, and the general average of 2000 ft per hour is only varied by the rig crew's ability and working conditions.

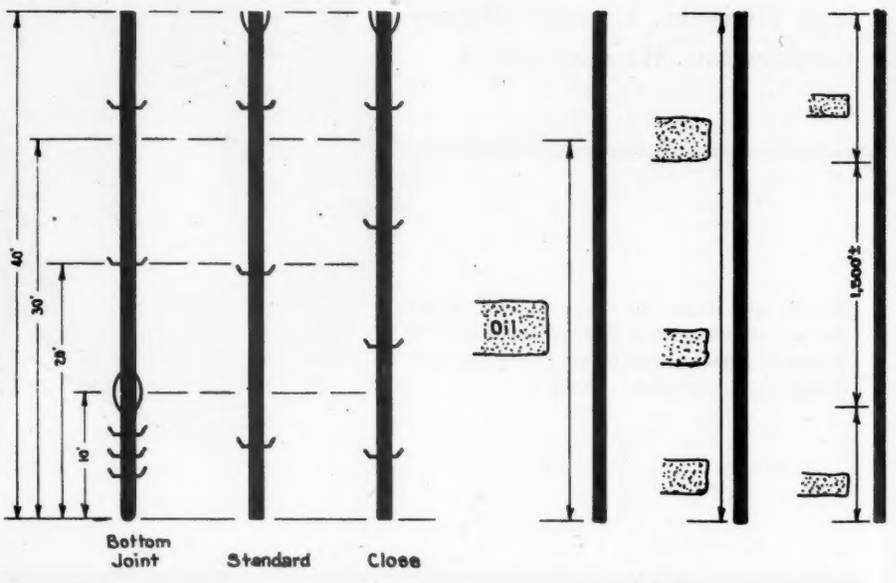
Scratcher Installation

Drill pipe is usually re-run to bottom, after the electrical log, and caliper survey or sidewall cores have been taken, to condition the mud fluid preparatory to running casing. Scratchers are most often installed on the casing during this period. From the electrical log, the uppermost productive sand is located, and the standard pattern shown in Fig. 1 extends from the casing shoe to above this depth.

An analysis of 100 recent casing jobs showed that an average of 840 ft of scratchers were installed. On Range 3 casing, averaging 40 ft, this would indicate that 21 joints were covered. These joints should be placed on 4-in. skids on the upper row, and sufficient working space should be provided. The scratchers are placed at selected intervals, usually 2, 3, or 4 per casing joint, and welded lugs spotted about 1-ft on each side of the scratcher to restrict its travel and to provide sufficient space for slip removal without reversal as each joint is raised from the rotary table or casing spider.

For the average job described above, the time required for installation would be about 3 hr. Lifting tools for raising the casing joint, adequate working space, good planning, and a fast welder will shorten the time required for installation. Three lugs are usually placed above and below each scratcher. If joints are rolled closely together, after the scratchers have been installed, a welder may place two of the upper lugs and two of the lower lugs, above and below each scratcher without moving any of the casing joints. All joints should then be rolled over 180 deg and the third lug placed above and below each scratcher. This suggestion has often reduced welding

FIG. 1.



Range 3 casing.

Scratchers and centralizers installation.

*B & W, Incorporated, Houston, Texas.
†Presented at the AIME meeting at College Station, Texas, on December 9, 1949.

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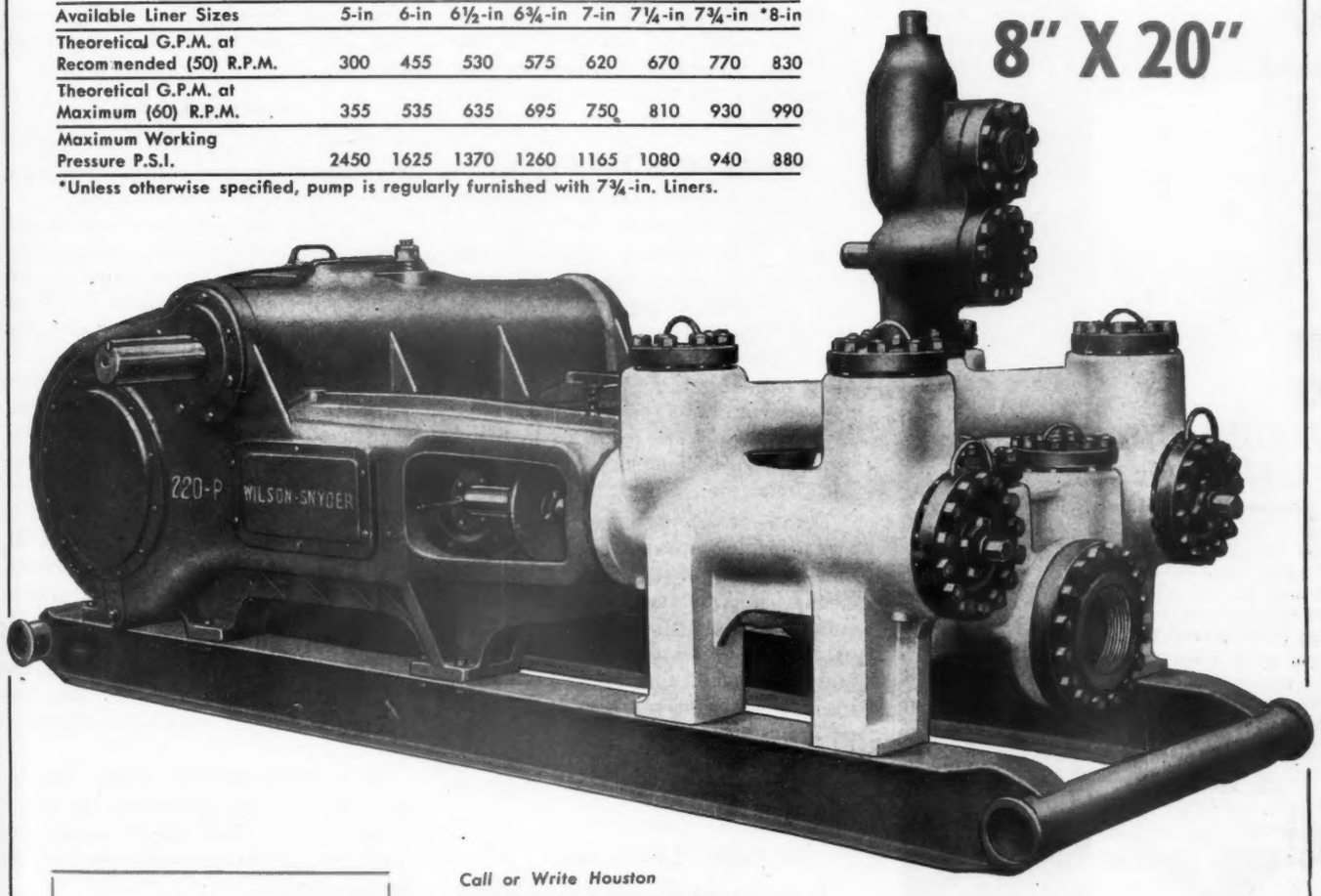
Theoretical G.P.M. at Recommended (50) R.P.M.	300	455	530	575	620	670	770	830
Theoretical G.P.M. at Maximum (60) R.P.M.	355	535	635	695	750	810	930	990
Maximum Working Pressure P.S.I.	2450	1625	1370	1260	1165	1080	940	880

*Unless otherwise specified, pump is regularly furnished with 7¾-in. Liners.

8" X 20"



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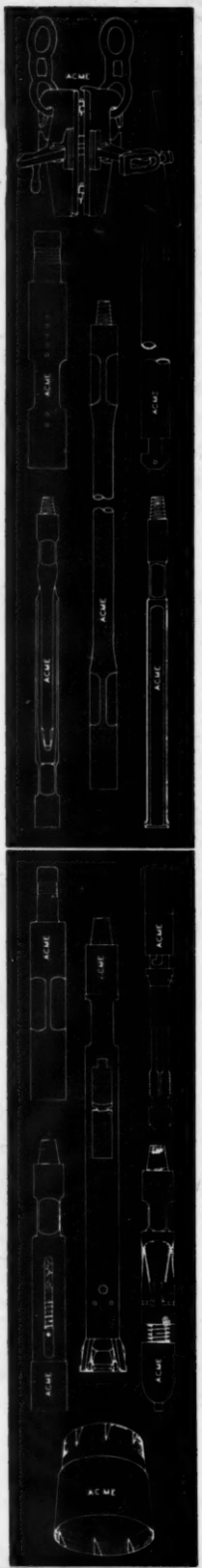

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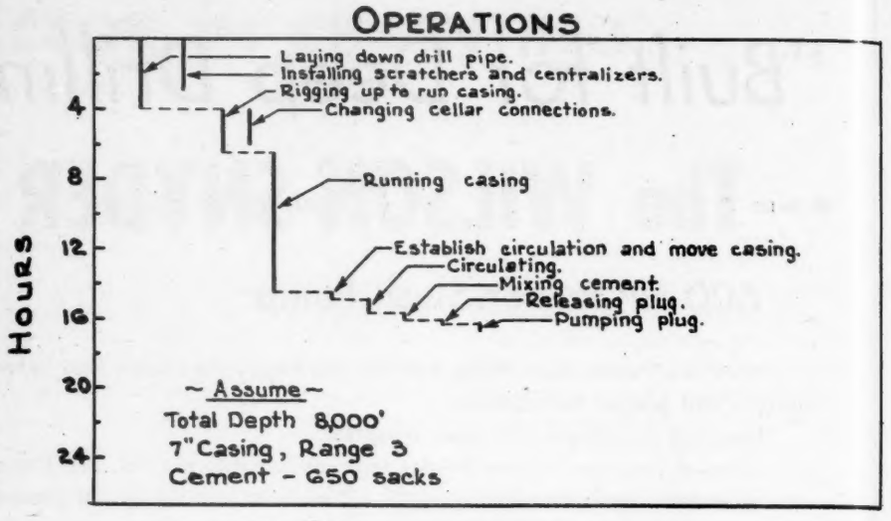

FIG. 2. Time schedule in cementing.

time by at least 50 or 60 per cent.

Solid collar centralizers should be installed while the casing is on the rack, but hinged centralizers may be installed on the rack or at the rotary table as casing is run.

Rigging Up To Run Casing

A great deal of work is required to make proper preparation for running casing. The addition of individual joints to the casing string is an operation of constant repetition, and the saving of seconds on each joint results in a saving of hours for the entire job. More men should be used than in the normal rig crew, and it is customary for crews to "work over" or to bring in a crew of specialists to provide the additional man power.

Details of rigging up include casing thread protector loosening or removal, measurement of the upper row of casing, making and installation of spinning and lifting lines, hoisting of stabbing board, and connecting and hanging of the flexible mud-filling line. Close supervision during this period is necessary for the enlarged crew to prevent break downs or other delays during the actual running of the casing.

Cellar Connections

A portion of the regular or casing crew is used to make the necessary changes in the cellar connections. Certain blowout preventers require changing of the inner assembly to provide a seal for the casing rather than the drill pipe that was used during the drilling operation. Improvements have been constantly made in these assemblies and the necessary changes can now be made during the rigging up period. Usage of equipment that requires an extended period for changing inner assemblies is not recommended.

Running Casing

There is a competitive challenge in running casing, and almost every crew tries to boost its former record.

No other rig operation requires the perfect team work of the casing crew. An experienced crew observes all safety rules and good supervision sees that safety is never sacrificed for speed.

The development of the round thread, the usage of a spinning line, improved hoisting equipment, and better facilities for filling the casing joints have speeded up the casing operation. Average running time for 5½ or 7 in.—range 3 casing on the Gulf Coast—is 1000 ft per hour. Assuming an average length of 40 ft per joint, this indicates that slightly more than 2 min is required for handling each individual joint. This time factor can be used to indicate running time for range 2 casing or other types of casing joint.

The availability of casing, during the past year, has influenced the selection, but a recent survey shows the following oil strings were run on 100 recent jobs:

5 in. — 4 6 in. —1 7 in. —55
5½ in.—36 6⅝ in.—1 7⅝ in.— 3

and that the casing joints were:

Range 1–1 Range 2–40 Range 3–59

Displaced mud circulation, provided by the use of a float collar or shoe on the bottom of the casing string, assists in conditioning the annulus as the casing is run. The volume of mud displaced as each joint is low-

ered is a constant check on the condition of the mud fluid and hole.

Actual Cementing Operation

A. *Circulation and Movement of Casing.* The establishment of circulation and the movement of casing as soon as bottom is reached, makes possible the continued movement of casing during the entire cementing operation, which is necessary to provide mud filter cake removal just as the cement slurry is passing the critical productive sections.

An analysis of the job reports submitted on an even hundred casing cementing operations shows the following:

	Hook up time	Mud circulation	Sacks cement used	Sacks cement per min	Install plug	Pump down
Max wtd avg	54	93	1500	30	..	..
Average.....	19	44	644	19	5	25
Min wtd avg	5	15	163	11	..	..

The chart shows that although it is possible to establish movement and circulation in as short a time as 5 min, the average time required is 19 min, and as much as 54 min is often required. The detailed record shows that the hazard of "freezing" casing increases as the time increases. Of the 100 jobs, 10 casing strings were frozen. The "remarks" on each of these jobs is important and are listed:

1. Took 25 min to fill, with casing one foot off bottom. Froze.
2. Well tried to blow out while circulating. Froze.
3. Seven inches at 10,000 ft, casing on bottom for 23 min while installing head. Froze.
4. Casing froze while installing plug.
5. Casing froze while installing cement head. Elevators 1½ ft above rotary table.
6. Seven inches at 10,072 ft, casing froze while installing bottom plug.
7. Casing froze while releasing bottom plug.
8. Casing froze while checking whether bottom plug was released from retainer head.
9. Casing froze while installing head. Casing only 1 ft off bottom at 10,000 ft.
10. Five and one-half in. at 12,459 ft, casing froze while connecting up and installing head.

As movement of the casing is essential to mud removal and better cement placement, it appears that improvement of our derrick floor practices for connecting up the cementing lines, in-

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stalling the cementing head, and releasing the cementing plug to reduce the number of frozen strings of casings is necessary.

B. *Mud Circulation.* The average time shown on the chart for circulating mud fluid after casing reaches bottom is 44 min. The general rule has been adopted by some companies of pumping a fixed percentage more than sufficient to fill the casing, while others circulate long enough to observe returns from bottom. The average figure shown is an indication that the shorter circulation period is more popular.

C. *Mixing Cement Slurry.* The chart also shows an average cement mixing rate of 19 sacks per min, the maximum rate being 30 sacks per min and the minimum rate being 11 sacks per min. The chart also shows that an average of 644 sacks of cement per job is used. These figures indicate that the average mixing time per job is 34 min. A mechanical cement mixer has recently been used on several Gulf Coast jobs and mixing rates of 43 sacks per min have been reported. Increased mixing rates will not only speed up the whole cementing operation, but should aid in keeping the casing full of cement slurry, and prevent the formation of air pockets to contaminate or interfere with proper cement placement.

D. *Installing Plug.* If the movement of casing is stopped, at any time after the casing string reaches bottom, there is a possibility that it cannot be moved again. The use of a plug retainer type cementing head has the advantage, over the total or partial removable type, of allowing the plug to be released without opening the casing to allow the admission of considerable amounts of air, and without setting the casing in the slips or releasing the elevators. Releasing the plug and changing the valves, with the retainer type cementing head, requires only a few seconds and can be done while the casing is still in motion.

The job analysis indicates an average of 5 min was required for installing or releasing the plug. Several casing strings were frozen during this critical period. The detailed record also shows that the movement of casing was stopped, on several jobs, while the cement was being mixed, and on several other jobs, no effort was made to move the casing after the plug was installed.

E. *Pumping Down.* The rig pumps are used, in most cases, to displace the cement slurry. Fluid velocities are at a maximum, during this period, because of the added weight of the cement column inside the casing.

The chart shows that cement is displaced on the average job in 25 min. This includes the time for the cement slurry to reach the casing shoe, the period up to equalization, and the pressure phase while the cement is entirely displaced from inside of casing.

Conclusion

The total elapsed time required, between casing reaching bottom and final displacement of the cement slurry, for the average of 100 casing jobs was slightly more than two hours. A movement cycle of about two min for the upward and downward travel of the casing indicates that about 60 strokes are made during the entire job.

This time study indicates no large saving can be made in rig time, but the saving of a few minutes during the critical period when the casing reaches bottom, and later as the cementing plug is released, are of extreme importance. A well planned program will provide closer synchronization of the movement of the casing with the travel of the cement slurry, around the bottom of the casing, and aid in increasing the percentage of successful cementing jobs. * * *

Releasing type fishing tools such as spears, sockets, overshots and cutters require downward blows for release of slips or grapples . . . and the handiest tool you can use to obtain downward blows when fishing with equipment of this type is the BOWEN Bumper Sub.

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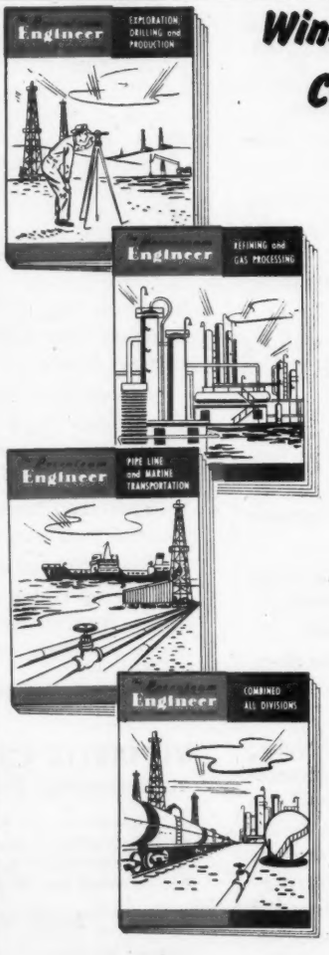

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The Contractor's Viewpoint

The Drilling Contract†

HAMILTON ROGERS*

ALL of you men in the industry have experienced the sense of creative effort that flashes through the depths of the mind when you drive up to a modern drilling rig and "see 'er a'turnin' to the right." There, before your eyes, are the symbols of the growth and development of a great industry on which all mankind and our nation's welfare so largely depend. In your mind's eye you can visualize the steady progress that has imperceptibly grown from the hours of sweat and toil, the adaptation to new conditions and techniques, and the expenditure of billions of dollars. It is only necessary to see these modern power plants in operation, drilling to depths below 15,000 ft, to appreciate the full contrast between them and Drake's first steam-driven rig in 1859 or the first crude rotary operation at Spindletop in 1901. Yes, "a'turnin' to the right" is the symbol to each of you of the transformation from the days of candle light to the days of vibrant society geared to wheels and propelled by machines that are oiled through your own creative efforts.

This progress—this transformation—has been possible only because of combined efforts of free men in a society of free enterprise. The individual operators, the independent companies, and the integrated companies by cooperative and competitive efforts have provided petroleum and petroleum products to meet the demands of a changing, materialistic world. All of these business enterprises—big and small—are essential to the future of the industry. Each is dependent on the other. None will ultimately survive without the other. An integral and essential part of this progress is directly attributable to the work and "know-how" of the drilling contractors. The technique of drilling wells is a science and an art—a specialized field of work and study for the independent drilling contractor. Today, approximately 85 per cent of the rotary drilling rigs are owned and operated by independent drilling contractors; their collective efforts, to be sure, have contributed substantially to the progress of world oil.

While progress in the discovery and development of these resources has stemmed, to an appreciable extent, from the independent contractual relationship between the companies and drilling contractors, the contracts defining that relationship have not kept pace with progress in the industry and have not evolved to reflect new and changing techniques, conditions, hazards, and methods of operation. Some of the provisions in drilling contracts today refer to practices and procedures long since obsolete and have no more place in a contract relating to a modern power rig operation than would an excerpt from the Code of Hammurabi. Changes have been made in contract terminology from time to time to guard aganst the effects of adverse count decisions, but in the main, these changes have been interpolated in the language of the contracts without recasting the whole agreements, and in consequence, these interpolations have often confused rather than clarified the relationship between the company and contractor. A house-that-Jack-built contract should not be recommended to the industry as a fair expression of the contractual relation between company and contractor, and certainly should not be used as the yardstick to determine risks and responsibilities in a contractual relationship involving the expenditure of thousands of dollars. It is for this reason that the contractors generally should doff their hats to the operating executives of the companies for their fair-mindedness and understanding in their uniform refusal to apply the "law of the Medes and Persians" specified in most of these contracts. If it were not for this understanding—this fair-mindedness — contractors could not work profitably under existing agreements. Probably, an ordinary company executive would be fired as an imprudent business man if he, in behalf of this company, repeatedly took the risk of a million dollar loss in order to earn a day-rate profit. But this is frequently required of the contractor. Such is his specified obligation in some of the contracts currently in use.

The conditions to which I refer occurred long before my time, but you men who have grown with the industry can recall favorably the days when a drilling contract was a simple understanding between company and contractor. To be sure, everything is more complicated now, and besides that, companies have had bad experiences with a lot of rugged individualists who followed the rigs, kept books in their hip-pockets, and slept near the boilers. These bad experiences led to complicated contracts, piecemealed from time to time with pocket additions designed to avoid a reoccurrence of the most recent experience, to the end that we now have patch-worked contracts, one sided in design, which do not reflect the ordinary, basic understanding between you men who have grown with the industry. Most of the contractors were efficient and reliable men, however, and in the cyclic economic experience of the industry, the inefficient are gradually weeded out. So during this same period, as the industry prospered and progressed, certain customs and practices grew to weld the understanding between the company executives and the contractors who worked for them. These are the customs of the industry today. So if I were asked to define a drilling contract, I might truthfully say that a drilling contract is that practical, though unenforceable, working agreement between the operating executive and the contractor that embodies the time-tested customs and the ordinary practices and procedures that have evolved during years of cooperative work and effort. But these customs and practices, particularly in reference to risks and responsibilities, are not always reflected in the printed agreements you contractors sign — probably with your tongue in your cheek and at the same time recalling that practical, ordinary working agreement between you and Mr. Brown, under which you think (and probably have reason to believe) that you will be bailed out if you run into heaving shale or other abnormal condition. The printed contracts simply do not reflect executive thinking. After all of these years of cooperative work, it seems that the basic, ordinary understanding between the operating ex-

†Presented at the ninth annual meeting of American Association of Oilwell Drilling Contractors, at the Baker Hotel, Dallas, Texas, September 19-21, 1949.

*Rowan Drilling Company, Fort Worth, Texas.

DEEP FRIO SAND IN OLD OCEAN FIELD MATAGORDA COUNTY, TEXAS

14

Mud (Caustic, Quebracho):
R_m = .55 @ B.H.T.
Bit Size: $8\frac{3}{8}$"
Spacings: AM = 16"
AM' = 64"
AO = 18' 8"

LOG ANALYSIS

1) Water saturation S

R_t = 8.5 ohms

Departure curves are necessary to establish the value of R_t in the sand from 10,128' to 41' because of bed thickness.

R_o = 1.2 ohms in adjacent wells where the sand is below water level.

$$S = \sqrt{\frac{1.2}{8.5}} = 38\%$$

2) Formation water resistivity R_w

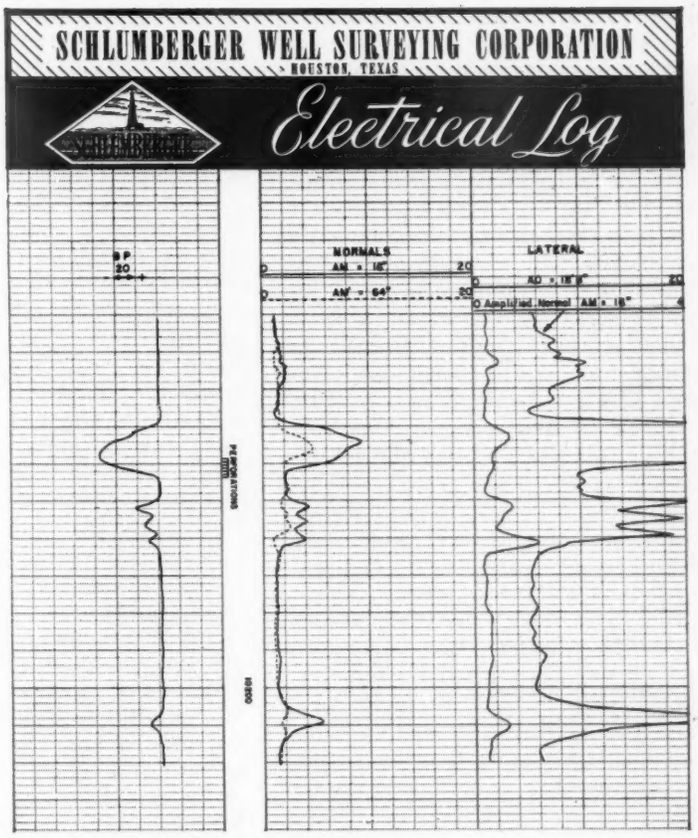
with $SP = -70 \log_{10} \frac{R_m}{R_w} = -60$ mv.,

R_w = .076 ohms @ B.H.T.

3) Porosity p

$$F = \frac{R_o}{R_w} = \frac{1.2}{.076} = 16$$

$$p = \sqrt[m]{\frac{1}{F}} = 21.5\% \quad \text{for } m = 1.8$$



CORE ANALYSIS

Average Porosity	24.3%
Average Permeability	248 md.
Residual Water	48.7%
Residual Oil	11.1%
Total Fluids	59.8%
Connate Water	37%

PRODUCTION RESULTS

Production Section:	10138—43'
Production Potential:	194.5 BOPD 37° API
Gas/oil ratio:	1141/1
Water:	25.1%

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ecutives and the contractors has not yet cleared the legal department.

The drilling industry is no longer in its infancy. It is full-fledged and man-sized and composed mostly of reliable business men who are worthwhile citizens and leaders in their communities, states, and nation. Just look around in the drilling industry, and you will see capable business men who have made a vast investment of risk capital in a risk enterprise and who regularly plow earnings into their business in order that the best of modern equipment can be offered their customers. They are not the "fly-by-night" contractors of older days; they are men who are financially responsible and whose integrity will compare favorably with the best in American industry. The prudent business man will not long risk capital in an enterprise that requires that he absorb catastrophe losses; his investment capital will be planted in safer fields. In the long run, the companies really cannot afford to hire imprudent contractors, for imprudence and incompetence often walk hand in hand. The progressive contractors have intricate systems of accounts and records that are required not only by common business prudence but also in order profitably to stay abreast under the highly competitive conditions that normally prevail. These business men have earned their spurs and should not be contractually penalized for the defalcations of the few. I have been told by older heads that you cannot write a contract that will really protect you against a defaulter; yet, it is the natural thing to do for lawyers to strive and strive and strive to that end. Real protection lies in the proper selection of business associates.

The drilling of a well is a hazardous and expensive undertaking. Recent developments in the law have accentuated old risks and created new ones. The intensive search for oil has brought about many changes in techniques, practices, and working conditions. The final settlement of accounts are frequently handled by clerks or auditors who are often unfamiliar with the practical aspects of the particular job, who do not know about the side agreement with Mr. Brown, and who discard old interpretations of contractual language and sometimes supply new ones. This whole changing panorama should prompt fair-minded business men in the oil fraternity to review the relationship between company and contractor and to rewrite the drilling contracts with a sprinkle of custom and practice here and a pinch of clarity, equity, and fairness there.

The companies and the contractors would mutually benefit if a uniform drilling contract were used that completely, accurately, and fairly specified the rights, duties, risks, and obligations of the respective parties. This is a long-range objective, difficult to achieve, which will require time and patience and practical knowledge and understanding. You see, it is difficult at times for lawyers to agree on contract terminology. Pride in authorship and honest differences in analysis or opinion only serve to complicate the problem. For the time being, therefore, it is urged that each company review its drilling contract and have it rewritten to fairly express those practical understandings that have evolved through years of experience and have become the actual practices and customs in the industry. The specific language utilized is unimportant if basic principles are fairly expressed and the actualities of modern operations kept in mind.

Consider, for example, the concept of "day work." In coring, drillstem testing, electrical logging, and other instances where work is normally performed on a day rate basis, the company has the right of control. If a packer fails on a drillstem test, the pipe is stuck, and the hole junked—who has the risk? Most of the printed contracts raise considerable doubt, or at best, the answer is in the "unsaid" section of the contract. Some of the contracts say that day work has no meaning or significance other than to designate the manner of payment, although court decisions seems to imply a significance of considerable importance. In spite of the "unsaid" section or the specific contractual definition, practical operating men say that by custom and practice the company takes the risk of the hole and the equipment in the hole while working on day work. If this is the practice—if this is the custom—would it be unfair to incorporate this principle in the printed contract?

Again, suppose the contractor encountered granite, high pressure water flow, heaving shale, or other abnormal drilling hazards before the specified depth is reached—who has the risk? Many of the printed contracts omit entirely any reference to abnormal hazards, and presumably the contractor would be required to drill through solid granite or fight heaving shale to the specified depth (and incidently tender the hole in acceptable condition) in order to earn his pay. Other contracts contain protection clauses that require the contractor to control high pressure water flow or similar hazard for a specified number of hours before day work begins but leave in the "unsaid" section the question of risk during the fight. Yet, when these conditions are encountered, practical operating men say that by custom and practice the contract is deemed complete, and all additional work is performed on day work at the risk and responsibility of the company. If this is the practice—if this is the custom—would it be unfair to incorporate this principle in the printed contract?

Take the "hold harmless" clause in most of these contracts—now that is the clincher! Although the contractor may have no direct liability, he contractually agrees to be liable and to protect, indemnify and hold the company harmless "from and against all claims, demands, and causes of action of every kind and character arising in favor of third persons on account of personal injuries and/or death or damage to property occuring, in anywise incident to, or arising out of the work performed by contractor, and particularly, but not by way of limitation, against any loss or damage whatsoever caused by fire, blowout, explosion, or accidents of any kind during the drilling and until the completion of the well and the acceptance thereof . . . and agrees to pay company for destruction of or damage to its property growing out of or incident to contractor's operations under the contract . . ." Practically everything that occurs around a drilling rig is "incident to or arises out of" the operations. The extent of assumed liabilities under this clause, both as to personal injuries and property damage, has not yet been fully explored, and as before the Elliff doctrine, will cover elements of risk and damage not presently enumerated among your worries. By such a broad, all-inclusive clause, the contractor in effect underwrites the whole show. The contractor is not an underwriter, never has been, and should not be. He should be responsible for his own negligence and the negligence of his employees, but he should not be contractually required to pay for the company's negligence or the negligence of company employees, or for the company's concurrent negligence. For example, if

* * *

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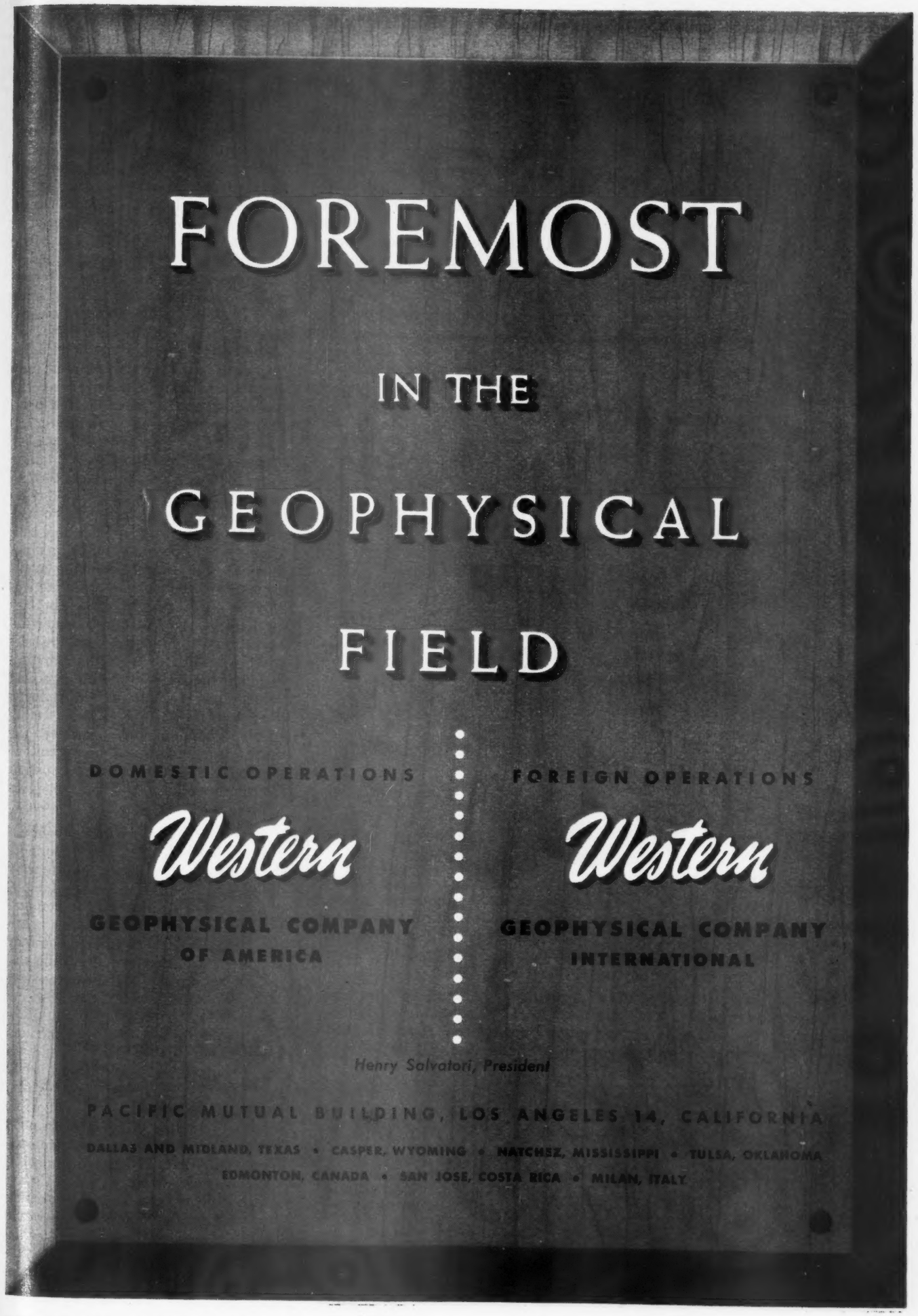
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the contractor is contractually obligated to carry mud weights in the manner specified by the company and does follow the specific directions of the company engineer, should the contractor be obligated to protect the company from a third party claim if inadequate mud weights is the established ground of negligence? The contractor may have a direct liability to the third party claimant, but he ought not be required to pay for the company's mistakes too. Some of the companies are to be commended for their recent amendments to the "hold harmless" clause. All of the companies should review this onerous burden. The oil companies will profit none by sitting astride Pandora's Box and screwing down the lid.

The Elliff case (Elliff vs. Texon Drilling Company, et al, 210 S. W. 2nd 558) announced new principles of law that amount to modification of the familiar "rule of capture". The contractor is primarily liable not only for underground trespass and damage to the reservoir but also for the value of the lost products which escape as a result of the contractor's negligence. The contractor's potential liabilities under the doctrine of this case are enormous. These liabilities are primary and direct and imposed by law, but when coupled with the "hold harmless" clause, the contractor must respond directly for his own negligent acts and indirectly for the negligent acts of the company. The drilling contractor is in a dilemma: He is exposed to unlimited liabilities on the one hand and cannot economically insure against the risk on the other. Although the insurance market has changed to some extent, I have seen one domestic quotation on a 20-rig operation amounting to $180,000 annual premium for $100,000 coverage. Such a premium is excessive and the coverage wholly inadequate for a catastrophe loss. The contractor cannot prudently take the risk of direct liability, and particularly the risk of assumed liability; so even though the company may not require insurance coverage, the contractor should consider the business advisability of securing insurance protection or else run the risk of having the earnings of a lifetime wiped out as a consequence of some momentary act of omission or commission. The "hold harmless" clause should be amended so that the contractor would be liable only for damages resulting solely from the negligent acts of the contractor or his employees during the time the contractor has the right of control over the operations. Should the company desire the contractor to assume any additional liabilities for underground damage or for value of lost products, the risk assumed should be covered by specified amounts of insurance, the indemnity limited to the amount of insurance specified, and the cost of insurance added to the contract price for the work performed.

Other parts of the contracts should also be changed. In so many instances the printed contracts are modified by odd riders, piecemealed amendments, and exceptions which lead to conflicting and ambiguous provisions when the whole instrument is considered; and in many instances, the difficulty in interpretations force across-the-table settlements after the work is completed. At times, the ambiguities and the "unsaid" portions of the contracts make analysis of risk and accurate billing and accounting difficult and provide a field for disputes that ought to be avoided. Although no contract could be designed to blanket all situations, clarity and completeness would certainly improve most of the contracts currently in use. Clarity and completeness—who does or pays for what, when, and where—would help the contractor analyze and evaluate each job and if the risks are equitably apportioned, will improve the relationship between company and con-

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tractor, and in the end will save the companies money.

Although the thoughts and suggestions expressed here are intended to represent the viewpoint of the drilling contractor, and to present the normal reaction to the typical drilling contract forms now in general use, nevertheless, the contractor is deeply conscious of the fact that his economic existence is essentially dependent on his continued ability to perform the basic services of an independent contractor. He is fully cognizant of the fact that he must—through the investment of increasing amounts of capital—provide and maintain equipment and facilities of the latest and most efficient design, sufficiently adaptable to meet the varied requirements of his customers.

He is also conscious of the ever-changing techniques of drilling, and of the competitive necessity for keeping abreast of the more advanced methods and practices in the industry, and of providing skilled labor and competent supervision with the required "know-how". Furthermore, the drilling contractor is aware of the fact that one of the primary inducements for the operator to contract wells in the first place, is to avoid a substantial amount of the operational risks and hazards inherent in the drilling operation itself.

In advocating a thorough renovation of the drilling contract form, the contractor is motivated by a firm belief that the accomplishment of this objective would materially aid him in improving his service to the operator and would inure to their mutual benefit. A contractual agreement that is clear and explicit as to the equipment to be furnished by contractor, the nature and extent of the service to be performed, and a definite and unmistakable pattern for the distribution of the specific risks and responsibilities, would undoubtedly improve the entire atmosphere and relationship between the operator's representatives and the contractor's organization—from the field personnel to the executive officers. Such an agreement would enable the contractor to intelligently and capably prepare his estimate—and to properly evaluate costs and risks of the undertaking, resulting in the submission of a more favorable price to the operator. Throughout the job, minor difficulties occasioned by uncertainty in the contract would be minimized. Upon completion, charges and billing could be prepared with a substantial savings in time and avoidance of needless corrections.

The executives and division superintendents of the operator would not be called upon to devote tedious hours to review the contractor's plight, as a result of the necessity for ameliorating the effect of hard and fast legal provisions—contained in many of the present contract forms—that are recognized as untenable in application.

If the disparity between the written contract and the real understanding, as determined by the more reasonable customs and practices generally followed, were resolved and clarified, the high cost of insurance resulting from premiums that are predicated on the false basis of the "letter of the contract" could be vastly reduced, and a satisfactory solution to the current insurance problem would be afforded.

Therefore, without presuming, nor intending, to write the contract for the operator, it is earnestly submitted that the oil operator, through its executive branches should outline and approve the basic principles for the new form of drilling contract, patterned along the lines and general principles, customs, and practices herein referred to, and that the legal department of the operator should be instructed to incorporate these principles into a new type of drilling contract form. * *

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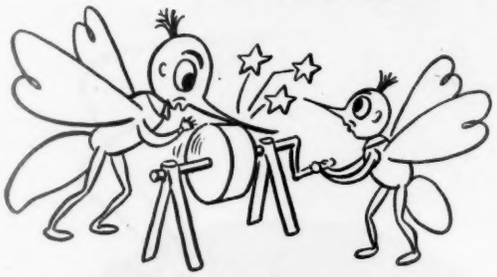

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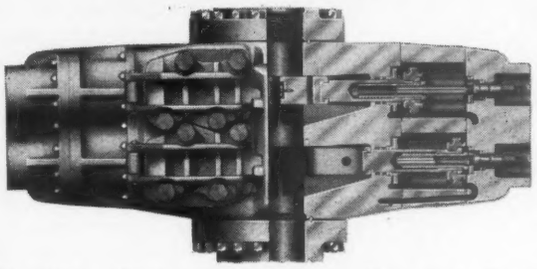

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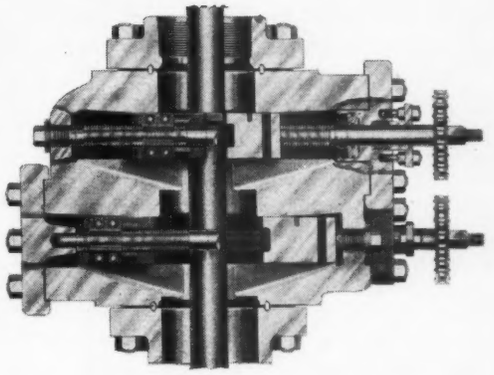

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Operator's Response

DRILLING CONTRACT FORMS†

EARL A. BROWN*

My task today is listed on the program as a response to Mr. Rogers' address on contract forms. I am supposed to present the matter from the operator's viewpoint. Trying to speak for all the operators has its elements of presumptuousness; so in the last analysis, what I say represents what appears to me, personally, and the company, which sometimes takes my advice as proper and practicable.

First, I should like to join Mr. Rogers in paying tribute to the spirit of fairness and understanding that characterizes the relationship between the contractors and the operators. This attitude has always been one of the outstanding features of the industry. Disagreements arising out of interpretations of the drilling contract have been rare; and when they have arisen, it has nearly always been possible to settle them amicably. It has been my lot to sit in on a number of conferences involving the construction of such a contract, and the settlements that resulted were invariably reached without any hangover of resentment by either party.

That isn't to say, however, that the drilling contract form should not be as complete, plain, and unambiguous as we can make it. It isn't to admit that there is any part of the contract that is not expressed in the written instrument; if there is, then the entire agreement is ineffective. A drilling contract should express the full agreement of the parties and be tested by the same rules which are applicable to any other contract in which the parties faithfully endeavor to express their mutual rights and liabilities.

This is necessary for several reasons. First, it is a protection to both parties, in connection with the performance of a complicated service involving the expenditure of large sums of money, to have their rights and duties clearly defined. Secondly, by keeping down misunderstanding, it serves to maintain the fine spirit of cooperation which now exists between the operators and contractors. Thirdly, clarity in obligation is absolutely necessary in cases where the contractual liability is covered by a policy of insurance. You can be certain that no insurance company will pay off on an "unsaid" provision of a contract, and you may be equally sure it will not assume any liability based on a custom or practice of the industry, unless that custom or practice is, in one way or another, clearly made a part of the written instrument. The basis of liability on the part of the insurance company is the written word of the contract, nothing else. It is highly important, therefore, that the contract be clear and complete.

There is another point in Mr. Rogers' address with which I am in thorough accord, and that is, some of the drilling contracts in force today are on patch-work forms. Deeper drilling, together with improved methods and more efficient processes in drilling operations within the last few years, have raised many questions not adequately covered in the drilling contract forms of a number of years ago. In many cases operators have tried to amend these old forms by adding a clause here and there to meet the new conditions, with the result that cohesiveness in expression and compactness in form have been sacrificed, to some extent. I might add, in this connection, that in my company we started several months ago to revise and redraft our drilling contract form to the end that it should become as clear, compact, and comprehensive as we could make it, and we hope to have it ready for the printer shortly. In every contract, however, there must be special clauses to meet unusual conditions. Provisions concerning the encountering of granite, heaving shale, or other abnormal drilling hazards are usually covered in such clauses.

Day Work

I come now to an issue in which I find myself in complete disagreement with Mr. Rogers. And that is concerning what he calls "the concept of day work"; and particularly his statement that: "In coring, drillstem testing electrical logging, and other instances where work is normally performed on a day rate basis, *the company has the right of control.*" (Emphasis mine).

Speaking for the form of contract my company uses, as well as those of several other companies I have examined, I find nothing that transfers the right of control to the operator when day work is being performed, except in certain specific and unusual cases. There may be times when an operator desires to take over the direction of the work when coring, drillstem testing, or other work of that character is being done, and, if the drilling contractor consents thereto, —and his consent must be obtained— then there is a change in the contract, or a novation to that extent, by mutual consent. The point to be emphasized, however, is that such right of control cannot be exercised in such cases by the operator without the specific consent of the contractor, in the absence of a breach of the contract.

Independent Contractor Relationship

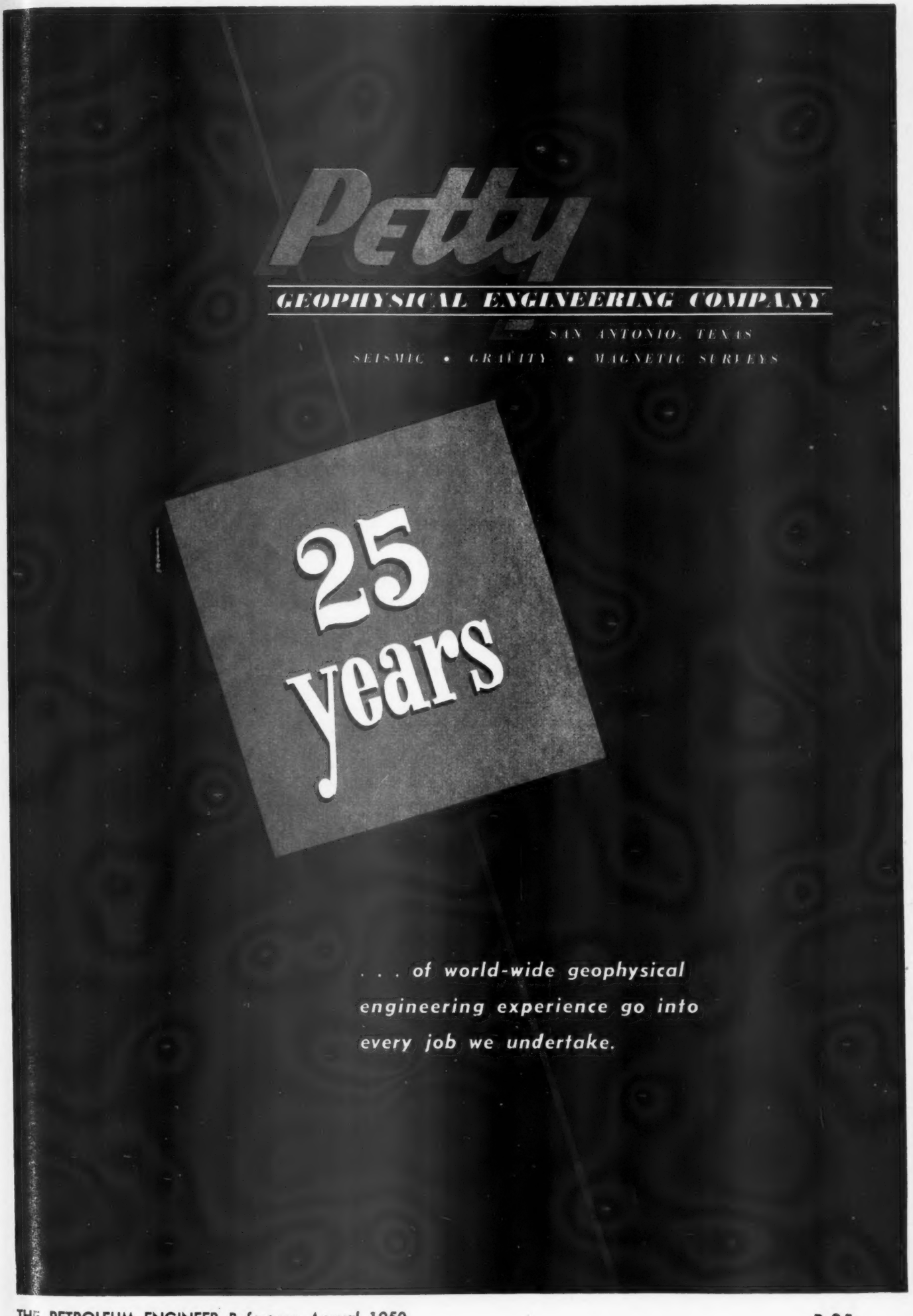
Probably the most important clause in the drilling contract, as affecting the rights of each party, is the "Independent Contractor" provision. Such provision is ordinarily stated, in substance, in these or similar words:

> "In the performance of the work hereunder contractor is an independent contractor, free of control or supervision by the operator as to the means and manner of performing such work, operator being interested only in the results obtained."

It is only logical and reasonable that the drilling contractor and oil operator should maintain independent relationships toward each other. They are engaged in different businesses. Each business is manned by employees especially trained for that business. The machinery and equipment required for the conduct of the one business is entirely different from that used in the other. The purpose of the one business is to drill and case a hole in the ground, and the purpose of the other is to produce oil through that hole after drilling is complete. The relationship between the two businesses is as distinct and different as that which exists between a contractor who constructs a building and a merchant who sells merchandise out of that building after it is constructed.

†Presented at the ninth annual convention of American Association of Oilwell Drilling Contractors, at the Baker Hotel, Dallas, Texas, September 19-21, 1949.

*Magnolia Petroleum Company, Dallas, Texas.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Each business, therefore, has its own responsibilities, and each should assume its separate obligations.

Right of Inspection

There is another matter, however, that requires mention at this point, and that is the operator's right of inspection of the contractor's work as it progresses. The mere fact that the operator retains the general right of inspection of the work as it is being conducted, for the purpose of seeing that the contractor meets the requirements and carries out the stipulations of the contract, does not change the relationship of the parties or make the contractor the agent and servant of the operator. In this respect we again find complete analogy to construction contracts generally. The erection of a building or the constructing of any project of a considerable size is invariably carried out in pursuance of an agreement which includes detailed specifications for the work. Such agreements always carry a provision permitting the owner to keep his representative, usually an architect or engineer, on the job to see that each part of the work as it is being completed conforms to the agreed specifications. Drilling contracts contain many provisions and specifications as to how the work shall be performed. It is certainly not out of the ordinary for the operator to retain the right of inspection of the work as it progresses, by his representative, who is often a geologist or a petroleum engineer (sometimes both), and to call the contractor's attention to any failure to carry out the contractual requirements. The legal rule covering this phase of the work is well stated in 27 Amer. Jur. 490, as follows:

> "The mere retention by the owner of the right to inspect work of an independent contractor as it progresses, for the purpose of determining whether it is completed according to plans and specifications, does not operate to create the relation of master and servant between the owner and those engaged in the work."

The authorities applicable to this relationship, and there are a number of them, make a clear distinction between the right of inspection and the right of control. This distinction is not altered by the fact that a contract may give the operator the right to stop the work when it is not being properly done. Stopping the work and controlling the work are not the same.

Cases sometimes arise, however, where it is claimed that the right of control is exercised by the operator's agent and inspector in contravention of the express provisions of the contract. The question is presented whether or not the legal relationship of the parties is changed by such assumption of authority. Such a case was that of Lone Star Gas Company v. Kelly (Tex. Comm. App.), 46 S. W. (2d) 656. In that case Lone Star Gas Company had employed Community Natural Gas Company, as independent contractor, to lay a pipe line. Kelly was injured as a result of the activities of Community Natural Gas Company in laying the line. Among other things he alleged that Lone Star had employed an inspector to inspect the work as it was being done and that the inspector exceeded the duties imposed upon him, and actually undertook to control the performance of the work by the contractor. This was denied by Lone Star and the evidence on the point was conflicting. The court, however, did not attach a great deal of importance to the inspector's activities, but said:

> "* * * in a case such as this, where the contract is conclusively established, the mere fact that the inspector may at times have exceeded his duties would not alter the legal situation. In other words, the relationship of master and servant depends *not on the exercise of control over the work, but the right to exercise such control.*"

Briefly then, the written contract of the parties prevails over the unauthorized act of the operator's inspector, in the absence of unusual circumstances. It follows, of course, that the contractor has the right to refuse to follow directions given by an inspector, when such directions are not authorized by the contract.

The "Hold Harmless Clause"

Probably the "hold harmless clause" has evoked more earnest comment and inspired more sharp criticism than any other provision in the contract. Mr. Rogers has given it a great deal of attention in his paper, suggesting that the contractor is required to "pay for the company's mistakes," and that by this clause "the contractor in effect underwrites the whole show."

Those expressions sound like somebody is endeavoring to force an unwarranted liability on the contractor, but let's examine the situation and determine first, whose "show" it is; and second, what the "show" includes. Answering the first question, I think it must be admitted that it is exclusively the contractor's show; he is the sole performer. The show is his agreement to "drill and complete" a well "free of control or supervision by the operator as to the means and manner of performing such work." Those provisions do not leave room or opportunity for anybody else to "get into the act." Again, while the statement of liability in the clause is expressed in comprehensive language, such liability is limited in the clause itself to that "growing out of or incident to contractor's operations under the contract." And when we remember that such operations are "free of control or supervision" by the operator, it may be that the clause is not as harsh or inequitable as might appear on first thought. Such a clause has been included in drilling contracts for many years, and history doesn't record that it has been an instrument of injustice in actual practice during that time. Finally, a careful reading of the clause fails to disclose anything that would impose liability on the contractor where the claims are based solely on the "company's mistakes." If such liability is included therein, then as a company attorney, I have been giving my client some bad advice for a long time and have overlooked some rare opportunities to pass on to the contractors some claims which I thought to be the responsibility of my company.

The Claim of Joint Liability

Seriously speaking, the principal objection which has been raised against the "hold harmless clause" is that it requires the contractor to assume full liability for injuries growing out of its operations jointly with some alleged act or fault on the part of the company. There is no denying that this is not only the effect but also the purpose of the clause. Upon first consideration this might seem unjust, but, again let's think the situation through.

Under Texas law the doctrine of comparative negligence is not recognized. Under such a doctrine, where two or more defendants contribute to an injury, the negligence of each is "compared," so that liability may be apportioned according to the degree in which the actors are considered to have been responsible for the calamity. In Texas, as well as in most other states, no such rule applies. In a typical case, McBeath v. Campbell, 12 S. W. (2d) 118, the Texas Commission of Appeals said:

> "There is no line of separation between the liability of joint tortfeasors. The tort is a thing integral and indivisible, and any claim for injuries arising therefrom runs through and embraces

every part of the tort. The liability of one cannot be carried into any portion of the joint tort that is not followed by an equal liability of the other tort-feasors. Each is liable for the whole, and the injured party may pursue one separately, or he may pursue all jointly, or any number less than the whole number."

It follows that where a third person, or his property, is injured and both the operator and contractor are charged with negligence, recovery for the full amount of damage could be had against either party, even though the negligence of one was slight as compared to that of the other, whose negligence was the principal cause of the injury.

Likewise, if a controversy should arise between the operator and contractor, growing out of damages suffered by one of them, a similar application of the same rule would prevail. If it could be shown that the negligence of the injured party contributed in even a small degree to the injury, there could be no recovery, because "contributory negligence is an absolute defense, no matter how negligent the defendant may have been." 30 Tex. Jur. 657.

It might be said here that a number of legal thinkers and writers have criticized the contributory negligence rule and the failure to recognize the comparative negligence doctrine, as applied in Texas and most of the other states, but they are still the law in these jurisdictions. So, when the operator and drilling contractor sit down to write a contract one of the things they try to do is provide against the harsh results that would follow from the application of these rules. And the only practical solution is to require the more active party to the contract to assume the full responsibility, and indemnify the other in case of loss. I don't suppose anybody would claim that complete justice is accomplished by this method. But it is submitted that justice is more nearly approximated, or at least, injustice eliminated to some extent, by such a contractual provision than would be the case if the parties should leave the determination of these questions to the common law rules.

After all, this indemnity clause does have a substantial basis. The contractor is in charge of the drilling operations; his contract gives him full control; it is his drilling equipment and machinery that are being used; and his own employees are performing the work. Whatever defects there may be in his drilling equipment are known only to him not to the operator. Whatever the skill or lack of skill, in drilling operations that is possessed by his workmen, is a matter peculiarly within his own knowledge. Whatever happens to be the value of his experience in drilling oil and gas wells is also a condition concerning which the operator may have little knowledge. Owing to the hazardous nature of the drilling operations, and the fact that the operator must pay a large sum for the drilling—wet or dry, and the circumstance that all operations are under the control of the contractor, it would be strange indeed if the operator did not insist upon a strong indemnity provision.

The McKee Case

The case of Standard Insurance Company v. McKee, 146 Tex. 183, 205 S. W. (2d) 362, decided by the Supreme Court of Texas in November, 1947, has been widely discussed because of its bearing on the relationship between the drilling contractor and the operator. It demonstrates (1) the importance of a complete contract between contractor and operator, and (2) what can happen in the absence of the indemnity clause.

The facts in that case were that Valley Osage Oil Company had employed McKee to drill several wells. McKee was an experienced driller, owned his drilling rig and tools, and for several years had been making contracts for the drilling of oil wells. He employed helpers who worked with him, paid them, and carried Workmen's Compensation insurance. The court says his agreement for employment with Valley Osage Oil Company "was partly written and partly oral," the written part consisting of a letter which provided that he should drill a well to a depth of 900 ft, stating the consideration and containing the contractor's agreement to furnish water, fuel, slush pit, and some casing, with the owner to furnish the oil string and pay for pipe lost in the hole. Two wells were drilled and the third one was not fully completed when the incident occurred that gave rise to this lawsuit. The pipe had been cemented in the hole and had stood for 48 hours when Branscum, Valley Osage's superintendent, told McKee to "go out, pick up the tools, dress the bit, and get ready to drill the new plug." The bit belonged to McKee and he went off to dress it, apparently using his own forge, and while engaged in this operation his clothing was ignited from fire in the forge, resulting in injury. There is no evidence that Branscum was present or gave any instructions about dressing the bit. However, the court found that Branscum gave certain directions about the drilling operations that amounted to assuming control, and this control was imputed to all of the acts thereafter performed by McKee. Quoting from the court's opinion:

> "It is true that Branscum did not tell respondent and the others working on the well how to operate the drilling rig or how to bail the hole. They knew how to do those things. But the testimony that has been discussed indicates that Branscum had control over the finishing of the well to the extent of giving all orders for the taking of each step, when to begin and where, how far to go and when to stop and how long to wait, and sometimes how to perform the work. This testimony, in our opinion, at least tends to prove that the employer had, after the pay lime was reached, a right of control that was authoritative rather than merely supervisory, and that it related not to the ultimate results alone, but also to the means and manner of performing the work."

It thus appears that by reason of directions given by the operator as to how far to go and when to stop, and how long to wait, a control was assumed by him that carried over into all other work, even to dressing the bit. Further on the court said:

> "The judgment rendered on the jury's finding that respondent was not an independent contractor when he was injured does not mean, as petitioner argues, that the contract for drilling the well terminated when the day work stage of operations began after the well had been drilled to the lime. Both the letter and the oral testimony prove that respondent was employed to drill and finish the well. The effect of the jury's findings is that the contract as evidenced by the letter and the oral testimony made respondent an independent contractor as to one part of the work under the contract and an employee as to the other part. One may entrust work to an independent contractor and retain such control over the doing of a part of the work as to create the relation of master and servant in so far as that part of the work is concerned."

To say that a person employed to drill a well may be "an independent contractor as to one part of the work under the contract and an employee as to the other part," and then to say that the dressing of his bit by a con-

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tractor in his own forge at a time when the operator was not present nor giving any instructions about the details connected with the dressing of the bit was, nevertheless, under the operator's control, has been a little difficult for some of us to understand, but it is, notwithstanding, a rule of law announced by the highest court in our State. It also indicates and implies that certain directions given by an operator to a contractor after the work is begun would create the relationship of employer and employee; when the same directions, set forth in a written contract between the parties prior to the beginning of the work, would not alter the relationship of independent contractor. Furthermore, the uncertainty as to the nature of the directions that would legally result in assumption of control by the operator emphasizes the necessity of a clear indemnity agreement in order that the liability of each party may be definite and certain.

Contractual Insurance

The usual drilling contract requires the contractor to carry some kind of insurance for the faithful performance of his contract along with public liability and workmen's compensation insurance. Following the decision by the Supreme Court in the case of Elliff v. Texon Drilling Company, 146 Tex. 575, 210 S. W. (2d) 558, on March 3, 1948, some of the companies that have been handling insurance for drilling contractors suddenly decided that their rates were inadequate for the character of insurance covered by their policies. They represented to the Insurance Commission of Texas that the Elliff case had created some new liabilities in connection with underground damage, and thereupon they asked for increases of all rates on underground damage and property loss, even though many of the risks included in their application were not even remotely connected with the facts on which the Elliff case was decided. In the Elliff case the facts were that Texon Drilling Company was drilling a well on the lands owned by Elliff et al, in Nueces County, Texas, when a blowout occurred and thereupon the well caught fire and cratered. The cratering process and eruptions continued until it spread to other wells which caught fire and burned and this loss went on for a period of nearly 10 years, that is from November, 1936 to June, 1946. It was claimed that Texon Drilling Company was negligent in failing to use drilling mud of sufficient weight in drilling its well and that such negligence was the proximate cause of the well blowing out. The jury found in favor of the plaintiffs and judgment was rendered in their favor for $148,548.19 for gas and distillate loss. The case was defended, said the court, on the ground that under the "law of capture" there would be no liability for loss of gas and distillate that escaped from the premises. The court held, however, that the "law of capture" would not apply where oil or gas was permitted to escape through negligence and fixed the measure of recovery at the value of the gas and distillate lost.

The insurance companies contended that they had heretofore depended upon the "law of capture" to protect them in case of this kind, and that this decision opened up a vast new field of liability that was either (1) not included in their policies, or (2) if so included, was not assumed knowingly. As a result they asked for increases in rates for all underground operations, including cleaning out, shooting, gun perforating, geophysical work, and other underground operations, in addition to drilling. And for good measure, and perhaps because they thought the time opportune therefor, they offered a substitute for the "hold harmless" clause in drilling contracts, which would relieve the insurance companies from liability in event it could be established that the operator's negligence may have contributed, even in the slightest degree, to the act that occasioned the loss.

The operators and drilling contractors joined their forces in what we felt to be the unwarranted demands of the insurance companies, and several hearings were had before the Insurance Commissioner. With the statement, or implication, of the insurance companies that prior to the decision in the Elliff case the "law of capture" precluded any liability for underground damage we took direct and vigorous issue. It has been the law in Texas for many years that one whose negligence causes underground damage to his neighbor's property is liable therefor. Comanche Duke Oil Company v. Texas Pacific Coal and Oil Company, 298 S. W. 554 (decided in 1927); Peterson v. Grayce Oil Company (Tex. Civ. App.), 37 S. W. (2d) 367 (decided in 1931), affirmed 128 Tex. 550, 98 S. W. (2d) 781. In these two cases adjoining landowners claimed underground damage to their properties through (1) negligence in shooting, and (2) negligence in the operation of vacuum pumps. In both case it was held that recovery could be had. The measure of damages, however, was not based on the amount of oil or gas which escaped by reason

of such negligence, but rather on the decrease in the value of the property damaged. It will be seen, however, that in presenting evidence as to the decrease in value of the adjoining property the principal evidence introduced would be to show how much oil or gas had been lost by reason thereof. Under either rule there would be little difference in the amount of the damage finally assessed. Therefore, we took the posifion that these cases had placed the insurance companies upon absolute notice since 1927 that they were liable for this character of underground damage.

The result of our hearing before the Commission was not as satisfactory as we would have liked for it to have been, the final outcome being briefly as follows: (1) The application of the insurance companies was rejected in part, especially as to those operations that were not included in the Elliff case and which the Commissioner found to have been theretofore covered by the insurance companies with full knowledge of the nature of the risk. (2) The application for a new rate on underground damage by blowouts etc. was rejected and in lieu thereof the Commission made this risk subject to an "a" rate, that means that the rate in each policy of insurance written is to be determined and approved by the Commission on the basis of the actual facts of the case. No action was taken on the suggestion as to the "hold harmless" clause.

At the conclusion of the hearing before the Commissioner we thought that substantial relief had been afforded against the demands of the insurance companies, but the results have been disappointing. In the individual cases submitted for an "a" rate the insurance companies were granted nearly all they asked for in the original application. This is true, although the industry offered a mass of evidence to show that in comparison to the number of wells drilled in the last fifteen years only a ridiculously small percentage of them ever had a blowout. The insurance companies offered no evidence to refute these facts. Also, we showed by uncontradicted evidence that the use of blow-out preventers and other improved methods, which have been put into practice during the last ten years —or since the Elliff well had its blowout—has materially reduced the possibility of such hazards.

The insurance companies refused to recede from their demands, however, basing their position entirely on the Elliff case—where the blowout occurred more than 13 years ago. (And I might say here that there has never been but one Elliff case and there will never be another.)

During the hearing, the Commissioner expressed the opinion that the rates asked by the companies were excessive, but said also that the Commission would have to take into consideration the possibility that insurance might not be available unless the insurance companies were willing to accept the rates which the Commission might find to be reasonable. Whether it was the threat the companies would refuse to write this character of insurance if they were denied the rates they demanded that induced the Commission to approve the high rates in the individual policies submitted to it, we do not know. All we know is the insurance companies got just about all they demanded.

The presentation of this matter to the Commission was handled by a special committee appointed by the Texas Mid-Continent Oil and Gas Association. The committee included representatives both of the operators and drilling contractors. On this committee, as well as in other points of contact between operators and drilling contractors, we found we could work in perfect harmony and with a common purpose. If I were called upon to select the two most valuable members of the committee, I should have to name the two men who represented the drilling contractors — Frank Lawshe and Will Morris. With their thorough knowledge of the problems involved and their almost inexhaustible store of information, their services were invaluable in preparing, assembling, and presenting the evidence we placed before the Commission. Mr. Morris himself took the stand and his testimony was as convincing and compelling as any I have ever heard in a proceeding or trial during all the years I have been practicing law.

It should be added that the committee on insurance has not been discharged. The temporary setback we received has not caused us to give up the fight. We are still hopeful conditions may develop by which contractual insurance may finally be secured at reasonable rates.

Conclusion

Drilling contractors and operators have one great fact in common, and that is that each will prosper only "so long as oil and gas, or either of them, is produced in paying quantities." Whether it is this urge of economic necessity, or the fact that there are so many swell guys in both groups that has brought on the spirit of understanding which now exists between them, I shall not undertake to say. I only know each group has a sympathetic interest and a thorough appreciation of the problems of the other group, and that this has brought about a real spirit of cooperation between the two. That doesn't mean that drilling agreements will not continue to be arm's-length contracts, but it does assure that neither party will demand a form of contract it does not deem to be reasonable, nor will either of them insist upon an unreasonable interpretation of a reasonable contract.

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New Practices for Eliminating Accidents in Offshore Operations*

J. B. GEORGE*

AT THE fifth annual Drilling Industry Safety Clinic in Dallas, Texas, almost every hazard on a drilling rig was touched upon in one fashion or another by the engineers, insurance men, drillers, tool pushers, and contractors attending. All of these hazards discussed here are present in offshore drilling and producing operations, but let's attempt to bear in mind that instead of being present on several hundred thousand acres of good ole West Texas sand and caliche, they are looking down your throat every day in from 30 to 70 ft of water. It is one whale of a big difference—this 30 ft or so of water makes so far as drilling oil wells is concerned. It makes a mighty big difference in a lot of respects; namely, costs, profits, time, service, insurance premiums, and last but not least, your accident frequency, severity, and loss-ratio rates.

It is an amusing thing how new obstacles in the drilling business can return your thinking to the past. In 1940, the height of the Illinois boom, I left Oklahoma with a crew to go to work up there. We were a young group of ruffians who were capable of holding our own whether it came to making hole or taking care of ourselves in the Saturday night honky-tonk circles, Indians or no Indians. Shortly after arriving in Illinois and making a payday, we set our sights on breaking into the Illinois social circles via the honky-tonk route. Shortly after arriving at the first joint our derrick man lowered the boom on one of the natives and was promptly ushered off to work for 60 days on one of the local civic sponsored pea farms.

After cultivating the Illinois peas for some two months our derrick man returned to work, made another payday and accompanied the crew on another visit to the local social clubs. During the course of the evening, he became involved in an argument with another native and drew back to again lower the boom. Just at the ins'ant of drawing back the sudden thought of the 60 days on the pea farm flashed through his mind, and with a great deal of reluctance, he shook his head and told his opponent that, " I would give a cool $100 to have you just 15 feet over the Oklahoma line." Several times within the past two years, I have heard good experienced drillers say essentially the same thing about the particular hole they were trying to make offshore.

Mental Strain

If you will carefully analyze the conditions surrounding an offshore drilling rig you will find one of the best set-ups for accident occurrences that can be found anywhere in the drilling business. First of all, it is essential that the men work 12 hr in a limited area instead of the usual eight hours oil field tour, due to transportation difficulties. Several psychological studies made in the past regarding fatigue have shown that fatigue occurs almost three times as rapidly during the last two hours of an eight hour day as was produced in the previous six hours, provided the work load was essentially the same. From this bit of statistical informaiton you can easily picture the situation where the tour consists of 12 hard hours instead of the normal eight. These 12-hr tours continue for a period of 14 straight days before the offshore employee takes a week off. In addition to the 12-hr day, the offshore roughneck and driller do not have available at their command the off-the-job diversions such as home life, picture shows, blonds, hobbies, and the various other types of entertainment that help a hard working man relax in preparation for the next day's work. Instead of all the comforts of home the offshore employee can only look forward to doing his own laundry and maybe get a few games of checkers or dominoes with some guy he has hustled iron with for the long, muddy, grimy 12 hr before. In fact, some of these employees engaged in offshore work become so thoroughly disgusted with being constantly associated with the same faces for 14 straight days that it really presents a problem.

These things are pointed out to show the mental frame of mind that it is quite possible for these men to carry to their 12 strenuous hours of work. Every man here is well aware that a majority of all accidents occurring on your drilling rigs today are the direct or indirect result of inattention or some bone-head stunt by a man who did not have his mind on the particular job he was endeavoring to accomplish. Whether you may or may not agree, I am convinced that a man's frame of mind, how he thinks and acts, as well as his personality traits and characteristics have essentially as much to do with our accident frequencies and insurance premiums today as all the guards, protective equipment, and safety rules that can be placed on a drilling rig. If this were not true, the National Safety Council would not annually attribute approximately 90 per cent of all industrial accidents occurring due to acts of individuals.

To cope with the situation of getting roughnecks and drillers to work in the proper frame of mind to offshore locations is not as easy as it might seem. There is not too much that you can do or furnish in the way of entertainment due to the fact that after 12 hr of hard work on directional holes a man is ready for some groceries and his bunk. The three most essential necessities to the offshore employee morale are:

1. Good food
2. Clean, comfortable quarters
3. Availability of diversified reading matter.

Now that we have discussed the mental aspects concerning the job, let's try to throw some light on the necessary physical qualifications.

Physical Qualifications

The physical qualifications of offshore employees are also important. The hazard of getting from boat to boat or from boat to structure in high seas is one that requires a great deal of agility, timing, and quickness on the part of the employee. This sort of maneuvering is not for the big, fat, clumsy, slow thinking, and slow moving individual. Neither is it for the aged, crippled, or sickly. Never before in the history of the rotary rig has the physical attributes of the drillers and roughnecks been so much in demand. Swimming must be a prerequisite of going to work as employees are constantly in danger of falling overboard.

†Presented at the fifth annual drilling industry Safety Clinic of American Association of Oilwell Drilling Contractors, at the Baker Hotel, Dallas, Texas, June 15, 1950.

*Safety director, The California Company, New Orleans, Louisiana.

If they cannot swim well enough to keep afloat until a ring buoy or heaving line is thrown, they will be carried under and chances are their bodies will never be recovered due to the treacherous currents moving around most drilling structures. The same caution should be exercised by casing crews, cementers, acidizers, tool companies, and other service firms sending men to offshore jobs. They should send the best physically capable men in their respective organizations. Several accidents occurring in the Gulf of Mexico have been sustained by service company employees who had absolutely no business being sent out there in the first place, due to the fact that they were physically handicapped, too old, or not physically capable of getting off of boats in rough weather. Letters should be written to service firms asking their cooperation in this matter.

Boats—Boats—Boats

Again you can safely say that never before in the history of the rotary rig has a drilling operation been so dependent upon a single thing as it is upon boats servicing an offshore operation. If you are going to drill offshore you might as well reconcile yourself to the fact that you are going into the boat business in one way or another. It is an expensive business too, and one that can make for many accidents if proper precautions are not taken from the beginning. To give you an idea of how quick you can get into the boat business in a big way, let's look at our own situation in the California Company. In April of 1948 we began rigging up for our first offshore venture. Today, a little over two years later, we are in the boat business to the tune of three and one-half million dollars annually. If you drilling contractor safety and insurance men think you are not going to have to become marine safety engineers, you are only kidding yourselves as I was a year and a half ago. During 1949, 60 per cent of the disabling injuries occurring in our Gulf Coast division, where we have about 40,000 bbl daily production, were related or directly connected with boats or marine operations. Twenty-two and one-half per cent of all disabling accidents in our entire company were sustained from the boat source during 1949.

In dealing with licensed seamen, engineers, and masters you are going to be associated with a group of individuals who, in the past, have been as far removed from oil field drilling and producing operations as roughnecks have been from pink teas. Their line of thinking is far different from any you have ever come in contact

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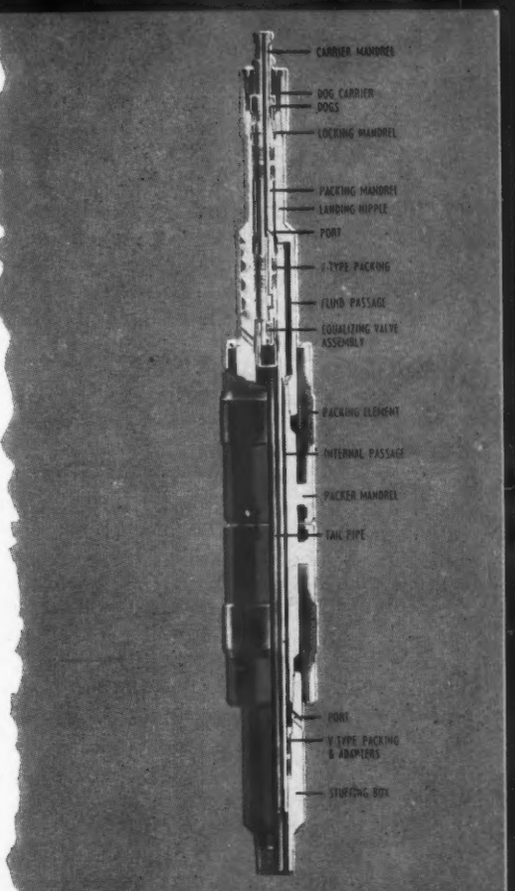

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with before in the oil field. They speak an entirely different language from that of us oil people and whether you like it or not you are going to have to learn the difference between port and starboard if you are going to accomplish anything from a safety standpoint with this group of men. My personal suggestion for becoming an "old salt" in a hurry is as follows:

1. Get a copy of Chapman's *Piloting, Seamanship, and Small Boat Handling.*
2. Get a copy of Turpen and McEwen's *Merchant Marine Officers Handbook.*
3. A set of U. S. Coast Guard regulations, Nos. CG-169 and CG-170, covering vessel inspection and pilot rules.
4. Enroll in the closest U. S. Power Squadron Coast Guard Auxiliary Piloting School and begin spending some nights with your new sailor friends aboard ship. They will be much more cooperative and amazed at the way you have learned the difference between a scupper and a yawl, and you will be amazed at how much more attention they pay to the few safety suggestions that you are capable of making.

When dealing with boats and boat personnel you can become associated with accident reports that have never been previously written into oil field annals in the past. Here is a sample of three reported in our company last year:

1. Deckhand lost time from work because of infection caused from being bitten by a crab.
2. Engineer lost time after his shoulder was dislocated from having nightmare in upper bunk.
3. Combination cook and deckhand lost time resulting from infection caused by stepping on a fish bone. It is a difficult problem to get these fellows to wear clothes, let alone shoes.

In all your safety, personnel, and related work with seamen in offshore operations, you must bear in mind that the Workmen's Compensation policy written for their coverage is strictly optional with them. If they decide that the compensation benefits are not ample, they have the right to sue personally in admiralty under the Jones Act in Federal Courts. If you are really trying to keep your loss ratio in line with your accident frequency and severity rates, this option of personal suit in the federal courts is one that will get you extremely interested in marine safety work if you are going to stay on the payroll.

When I first began roughnecking, an old timer told me that if I was smart I would get out of the oil field while I was still young. When I asked him, why, he told me that the drilling rig was fast being taken over by kinfolks and football players. If I could see this old timer today, it would be easy for me to tell him that the sailors have moved in along with the kinfolks and football players.

Handling Materials

After transporting drill pipe, casing, mud, cement, and other bulky supplies out to an offshore structure, you are confronted with the hazard of getting them from a barge to the structure or tender. About the best precaution that can be taken in eliminating this hazard is to observe your weather forecast exceedingly closely and anticipate your supply needs as far in advance as possible. We all know, however, that oil field people are not going to stand by and watch a $4000 a day rig stay shut down long waiting for pipe, cement, mud, and other supplies. During certain times of the year it is possible to go for days and not have under a four and one-half foot sea. In times like this, you simply have to make the best of the situation and take all the precautions possible.

In removing tubing, casing, or drill pipe from a barge to structure or LST during fairly rough weather, you must have sufficient manpower to handle enough tag lines to keep the pipe under control as it is picked up by the winch and boom. In rough seas, it is often necessary that every man assigned to the operation be called out to help with the heavy material handling. This involves a lot of overtime which is difficult to explain to management, but to insure any degree of safety, the overtime is a must. The operation, as well as the snubbing and maintenance of these winches and booms by experienced personnel is mandatory if wholesale injury is to be averted. In not being too familiar with rigging operations in the beginning, we made the mistake of using 6 by 19 wire rope which caused three accidents because the stiff line would not spool evenly on the winch drum. A change to 6 by 39 wire has eliminated this hazard without losing any appreciable safety factor in the stress of the line.

It seems that I have discussed almost everything relative to the hazards of offshore work except the drilling operation itself, but the greatest difficulty encountered thus far has been the supply problem. This is quite natural, since it is really the new phase of the business to all of us.

Safety Precautions on Rig

Due to the fact that most of this talk has been devoted to everything but drilling does not mean that certain precautions are more necessary than they are on land. Your guard rails, for instance, must be higher and offer more protection than around the ordinary land substructure. The drawworks and rotary table are 46 ft above the water on most of our structures which will give you some idea of the seriousness of the guard rail problem. One really serious accident occurred due to a roughneck falling over a 42 in. guard rail on the pipe rack. On future jobs, we are going to build a "Cyclone" fence for protection around both sides of the pipe rack. On the end where the pipe is brought from the tender, an 8-ft cyclone fence is to be installed horizontally to act as a net for any employee falling off the end of the pipe rack.

Many other precautions must also be taken. Water should be going into the exhausts of all internal combustion gas engines or they should be equipped with a suitable water jacket to keep the exhaust cooled below the ignition temperature of gas and petroleum vapor.

We have recently installed derrick safety slides by driving an additional piling about 200 ft out from the main structure. This presents a hazard, though, as a boat might run into the slide line at night and pull the derrick down. Some type of illuminating paint is needed to paint the last 50 ft of line.

Your light plant, lights, and all electrical wiring should be of the approved type of electrical equipment.

Our fire protection during drilling operations consists of water and CO_2. The static head at all fire outlets aboard the LST is 80 psi with an auxiliary unit standing by, that can boost it up to 145 psi. Other than water, we utilize many portable hand CO_2 extinguishers. After the rig has moved off, the producing equipment is protected by an Ansul 150-A truck mount and two Ansul 30-lb dry powder extinguishers. The 150-lb Ansuls are equipped with 100 ft of hose instead of the usual 50 ft.

G. M. Kintz, U. S. Bureau of Mines, has been very cooperative in helping with his new 10-hr first aid training course. First aid training at offshore operations is more important than at any place I have ever seen in the oil fields. It is often very difficult to hold classes on schedule due to the work load. Kintz's engineer was very cooperative in working with our supervision and we were successful in having approximately 240 men complete the 10-hr course despite many obstacles. * * *

Main operating units in Cymric field plant. Left to right are the absorber tower, deethanizer-reabsorber tower, still, and product fractionator.

The Cymric Absorption Plant*

A unit of high LPG recovery is efficient when richness of gas is increased by lowered reservoir pressure.

F. H. LACY, JR.[1] and WARREN H. KRAFT[2]

DURING 1946, the Superior Oil Company, Standard Oil Company of California, and Honolulu Oil Corporation concluded an agreement to install a joint gas-gathering system and a compressor plant in the Cymric oil field of California. The initial gas-gathering layout consisted of a 425-lb high pressure system and a 25-lb low pressure system. Compression of the low pressure gas was carried on in two stages, with a final discharge pressure of 425-lb. At a later date an intermediate, or 125-lb gathering system, was installed. Honolulu Oil Corporation was designated as operator of the facilities, and the operating agreement provided that an absorption plant would be built at a date when economics warranted the investment.

The high pressure gas-gathering system was put in operation in June 1946, and the compressor plant and low pressure gas-gathering system began handling gas in November 1946. Surplus gas above field fuel requirements was delivered to the gas purchasing company after suppression of its dew point by cooling.

During the latter part of 1947, as market conditions for LPG and natural gasoline improved and better estimates of the future reserves and gas rates to be expected from the Cymric field became available, a study indi-

*Presented at the regular monthly meeting of California Natural Gasoline Association on November 3, 1949.

[1]Gas engineer, Honolulu Oil Corporation.
[2]Manager of gas and gasoline operations, Honolulu Oil Corporation.

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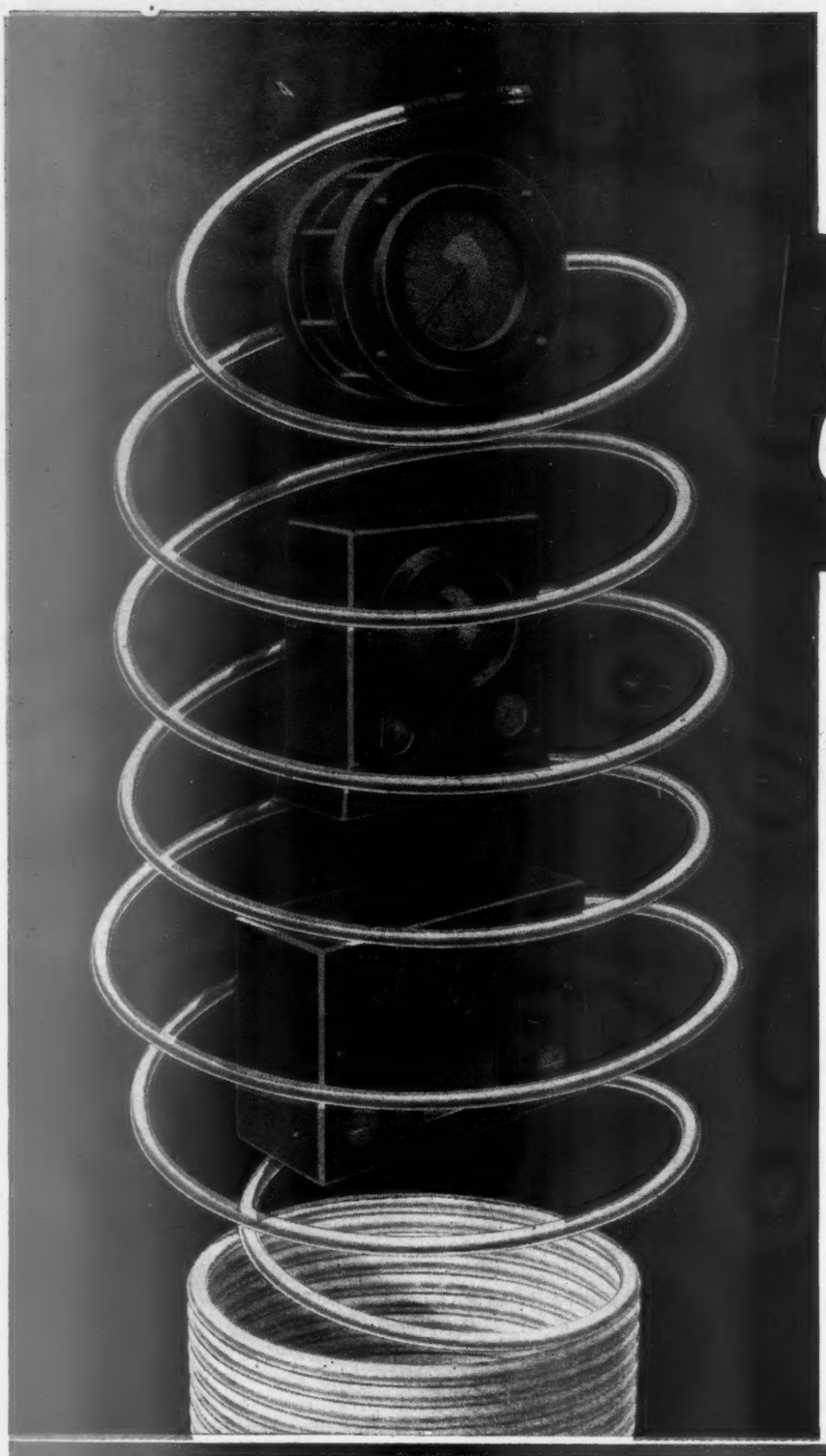

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Application of a simple and extremely efficient process-flow to the special problem of a rapidly declining plant load, and careful attention to equipment selection, costs and layout, made the installation of a "marginal" gasoline plant in the Cymric field, California, an economically sound project.

cated that a payout on an absorption plant was possible. Another, and probably the biggest, contributing factor was the increased richness of the gas insured by declining reservoir pressure and a consequent shift in the ratio of low pressure to high pressure gas. The problem then, as in so many cases, became one of designing and constructing an absorption plant as rapidly and economically as possible.

The approximate amount of capital that could be risked was agreed upon and as the cost of an absorption plant is recognized as being largely a function of the total oil circulation rate, a study was made of a plant with limited oil circulation that would meet the following process requirements:

1. Handle an initial high gas rate of lean gas through the absorber.
2. Effect a maximum recovery of gasoline and liquefied petroleum gas when the gas load was reduced and the gas richness increased.
3. Use a minimum of fuel gas, cooling water, and electricity.

The basic study with its correlative analysis of various processing cycles proposed to meet the above plant requirements, consumed the remainder of 1947 and early part of 1948. In February 1948 a decision was reached to install a plant with the process cycle illustrated in the accompanying flow sheet. Design calculations indicated that the plant would:

(1) Handle an initial gas load of 35 to 40,000,000 cu ft per day of lean gas.

(2) Effect a maximum recovery of butanes plus and a relatively high recovery of propane from 15,000,000 cu ft per day of rich gas.

(3) Be capable of recovering 85 to 90 per cent of propanes from 15,000,000 cu ft per day of rich gas with only minor additions to the initially installed equipment.

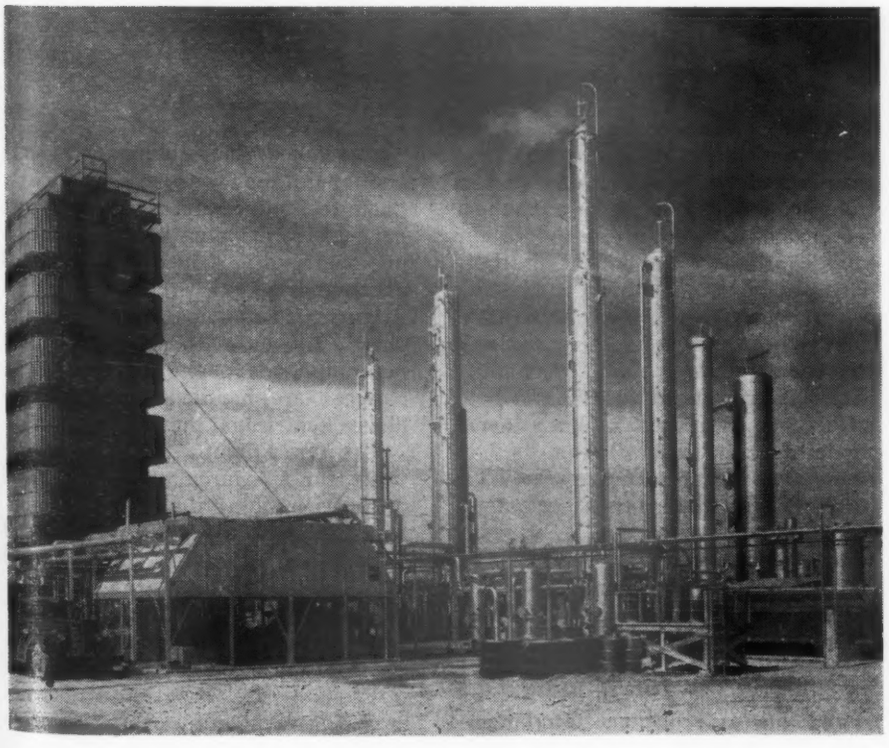
(4) Retain at least 90 per cent of the propane recovered at the main absorber under any and all conditions of plant operation.

(5) Be able to produce either specification Butane-Propane mixture or propane as desired.

(6) Meet the required economy on fuel, electricity, and water.

Ground was broken for the plant in May 1948 and product streams first run to storage on November 11, 1948.

View of compressor plant in Cymric field, California



General Plant Flow

At the present time, due to declining field pressure, all gas is gathered at either 25 or 125 lb. The compressor plant handling this gas consists of five gas engine driven units totaling 2960 hp. All jacket-water cooling is done by radiators. After cooling and scrubbing, the rich gas passes through a single main absorber, and from there to sales, field fuel, etc. The rich oil from the main absorber is fed cold to a combination rich-oil rectifier and reabsorber. This unit is side heated by oil-to-oil interchange, and uses a vapor stream from the still reflux accumulator for rectification of the rich oil. The overhead vapors from this column are used for plant fuel. From the bottom of the combination rectifier and reabsorber the rich-oil passes through a second oil-to-oil heat exchanger on its way to a single high-pressure stripping still. Heat is applied to the still by a re-circulation direct-fired side heater. Part of the still overhead is condensed as a de-ethanized liquid product—with the remaining vapors being returned to the combination rectifier and reabsorber for rectification service. The resultant de-ethanized liquid product is fed to a single conventional fractionator. This column operates totally condensing, with an overhead product of specification LPG, and a gasoline kettle product.

With this general plant flow in mind, we can consider some of the major units in greater detail.

Main Absorber. The main absorber is designed to operate at 425 psig. It is equipped with 24 perforated plates specially designed to maintain high absorption efficiencies over a wide range of loading. Original operating guarantees called for a total butanes recovery of 60 per cent at a 30,000 Mcf per day rich-gas rate when circulating 171 gpm of 180 molecular weight lean-oil at lean-oil and rich-gas temperatures of 80 F. Plant tests show this column exceeds its 30,000 Mcf per day efficiency guarantee by a substantial margin.

The column is equipped with a side draw-off tray that will be used for intercooling the absorber if and when it is desired to achieve propane recoveries of the order of 85-90 per cent at the storage tanks. To achieve these high propane recoveries, the only addition needed to the present plant equipment is the installation of a side-circulation pump and associated gas and oil chilling units. Propane absorption recoveries of 93 + % at a 15,000 Mcf per day rich-gas rate are anticipated with present oil rates on chilling of the rich-gas and absorber side-circulation streams to 65 F.

Combination Rectifier and Re-

absorber. The combination rectifier and reabsorber is designed to retain, under all conditions of absorber operation and intake-gas volume and composition, 90 plus per cent of the propane content of the combined stream of rich-oil and compressor-plant condensate while so deethanizing this stream that the resultant fractionator feed contains not over 2½ per cent of ethane in its propane and lighter fraction. Design oil-circulation to the reabsorber was 35 gpm at a plant intake rate of 30,000 Mcf per day rich-gas—or 20 per cent of the main-absorber oil circulation. In actual operation, this per cent of reabsorber oil holds the ethane content of the propane and lighter fraction of the fractionator feed to between 1.5 and 2.0 per cent with propane retentions of 90 plus per cent.

Side-heating of the rectifier is used in combination with the re-circulation of rectifying vapors between the still-product accumulator and the rectifier base. This avoids both the high final lean-oil temperatures associated with the conventional base-heated rectifier cycle and the employment of expensive secondary heat-exchange circuits for heat conservation.

The rich oil from the absorber enters this unit cold at the top of the rectifying section. A recirculating side-stream is withdrawn from an intermediate rectifier tray and pumped through a side-heating interchanger on the hot stripped lean-oil stream. Rectifying vapors from the still accumulator are fed to the base of the unit. Control of the side-heater temperature is maintained by a temperature-actuated bypass valve on the hot lean-oil at the still-feed pre-heating interchanger, while the volume of rectifying vapors is controlled by controlling the temperature in the still reflux accumulator.

By proper mutual adjustment of the rectifier temperature and rectifying vapor volume, it is possible to automatically control the ethane-propane ratio in the fractionator feed within close limits for wide and relatively rapid changes in intake-gas composition and volume such as experienced at certain times of the year at Cymric between a hot afternoon's operation and the following cold early morning's operation.

As in the main absorber, specially designed perforated plate trays are utilized in the combination rich-oil rectifier and reabsorber to attain high efficiencies over wide ranges of column loading.

High Pressure Still. Because of the need to return rectifying vapors from the stripping still accumulator back to the rich-oil rectifier, the stripping still at Cymric is operated at approximately 115 psig. This vessel uses four separate tray designs. Exchanger preheated feed is introduced in the middle of the column. The partially stripped oil is withdrawn at a point several trays below the feed tray, pumped through the fired heater, and returned to the column. Stripping steam, side water-drawoffs, and cold reflux are employed in the conventional manner. Lean oil from the bottom flows under still pressure back through the still-feed heat exchanger, rectifier side-heater, and first stage water coolers—after which it is picked up by the lean-oil circulating pump, forced through a final water cooler and returned to the absorbers.

Product Fractionator. In order to hold capital expenditure to a minimum, only one product fractionator was installed. This column is of conventional design with accessories adequate to produce either a butane-propane LPG or commercial propane as an overhead product, and natural gasoline as a kettle product.

Pumps. Lean oil and cooling water circulation duties constitute the main pumping loads for the plant, and these services are handled by gas-engine driven centrifugal pumps.

The three pumps required respectively for side-circulation of rich-oil at the rich-oil rectifier, feeding rectifier bottoms to the stripping still, and recycle of partially stripped oil through the still fired-heater, are operated in tandem by a single steam-turbine. The exhaust from this turbine is utilized for reboiler service at the fractionator. By proper adjustment of its exhaust pressure, this turbine's

TABLE 1. Main absorber operation.

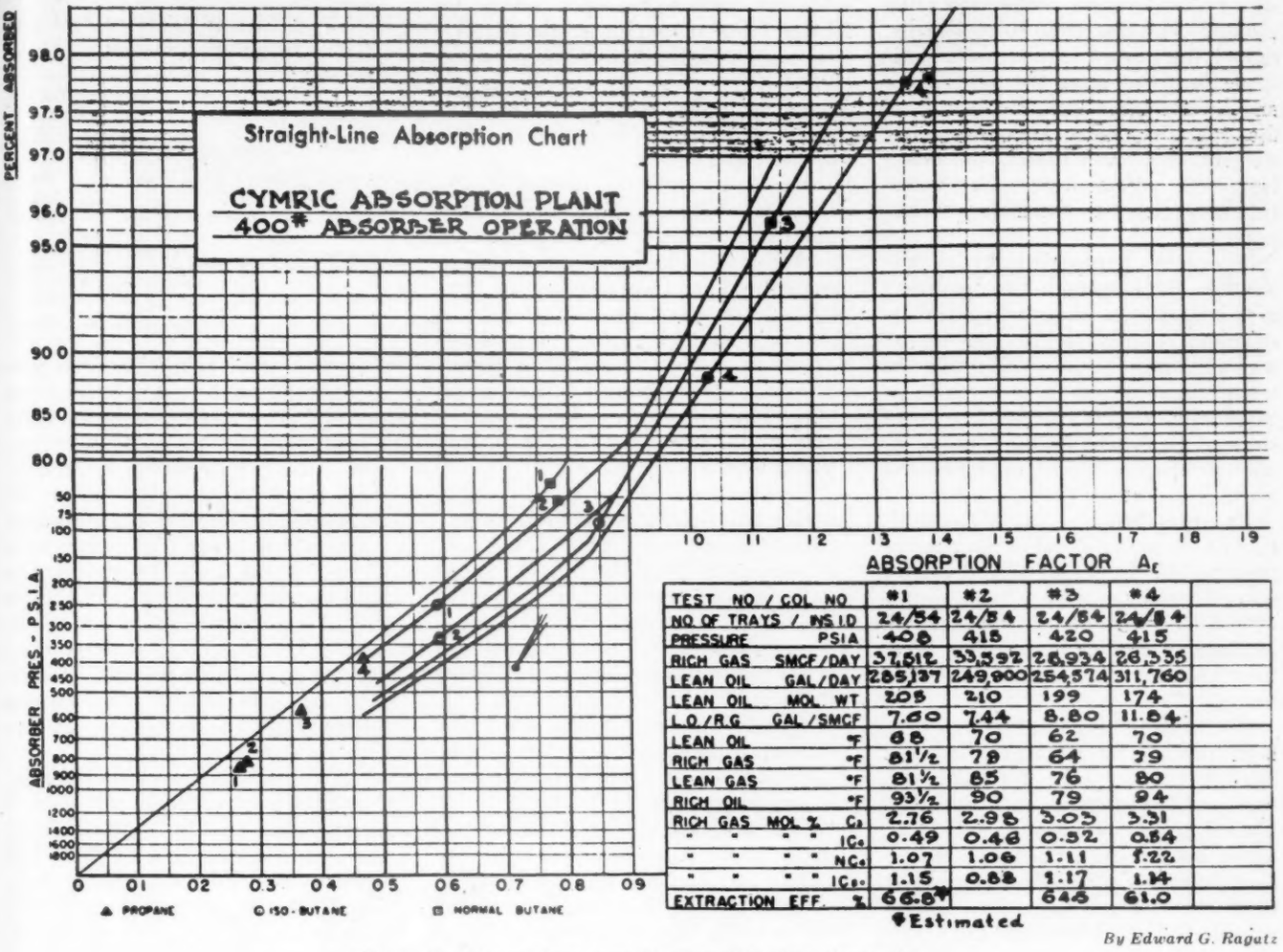
Test number		1	2	3	4	5†
Pressure	PSIG	393	400	405	400	400
Rich gas	SMCF/day	37,512	33,592	28,934	26,335	15,000
Lean gas	SMCF/day	35,800	32,000	27,149	24,210	13,000
Lean oil	Gal/day	285,137	249,900	254,574	311,760	310,000
Lean oil	Mol wt.	205	210	199	174	175
Lean oil	API	37.2	36.8	38.7	39.9	39.9
Lean oil/rich gas	Gal/SMCF	7.60	7.44	8.80	11.84	20.7
Lean oil temp.	F	68	70	62	70	70
Rich gas temp.	F	81½	79	64	79	80
Lean gas temp.	F	81½	85	76	80	82
Rich oil temp.	F	93½	90	79	94	96
Rich gas comp.	Mol per cent					
	H_2O	0.14	0.12	0.07	.....	.....
	CO_2	0.90	1.00	0.75	1.60	2.22
	C_1	87.87	87.61	87.36	85.84	81.88
	C_2	5.62	5.89	5.99	6.35	7.31
	C_3	2.76	2.98	3.03	3.31	4.30
	iC_4	0.49	0.46	0.52	0.54	0.75
	nC_4	1.07	1.06	1.11	1.22	1.72
	iC_5	1.15	0.88	1.17	1.14	1.82
	Total	100.00	100.00	100.00	100.00	100.00
Absorption	Percent					
	C_3	21.8	23.3	33.7	44.4	80.0
	iC_4	55.4	48.3	71.1	88.1	99.0
	nC_4	76.9	74.9	95.8	97.8*	99.0

* Estimated nC_4 absorption; test data showed 100 per cent.
† Anticipated 15,000 MCF/D operation without side cooling.

TABLE 2. Rectifier—reabsorber operation.

Test number		3	4
Pressure	PSIG	105	105
Discharge gas	SMCF/day	815	920
Discharge gas	F	.....	78
Lean oil to main absorber	Gal/day	254,574	311,760
Lean oil to re-absorber	Gal/day	52,840	54,288
Lean oil to re-absorber — per cent of lean oil to main absorber	.....	20.7	17.2
Compressor condensate	Gal/day	1,850*	3,190
Compressor condensate	Liquid per cent		
	C_1	0.14	0.18
	C_2	0.75	0.51
	C_3	3.00	1.63
	iC_4	1.86	1.39
	nC_4	6.46	3.59
	iC_5	87.79	92.70
Rich oil to rectifier	°F	79	94
Rich oil to side heater	°F	107	118
Rich oil from rectifier bottom	°F	175	173
Recycle vapor	SMCF/day	2,065	2,520
Recycle vapor	°F	135	132
Propane in rectifier feed retained in liquid product	Percent	91.1	89.8
Ethane in propane and lighter fraction of liquid product	Percent	1.42	2.06
Lean oil from exchangers to coolers	°F	124	133
Plant production			
Gasoline	G.P.D.	20,283	18,695
Gasoline	R.V.P.	24.6	20.3
LPG	G.P.D.	15,470	18,625
LPG	V.P.	128	118
Total liquid product	G.P.D.	35,753	37,320

* Calculated from plant balance.



TEST NO / COL NO	#1	#2	#3	#4
NO OF TRAYS / INS I.D	24/54	24/54	24/54	24/54
PRESSURE PSIA	408	415	420	415
RICH GAS SMCF/DAY	37,512	33,592	28,934	26,335
LEAN OIL GAL/DAY	285,137	249,900	254,574	311,760
LEAN OIL MOL WT	205	210	199	174
L.O./R.G GAL/SMCF	7.60	7.44	8.80	11.84
LEAN OIL °F	68	70	62	70
RICH GAS °F	81½	78	64	79
LEAN GAS °F	81½	85	76	80
RICH OIL °F	93½	90	79	94
RICH GAS MOL % C_3	2.76	2.98	3.03	3.31
" " " " IC_4	0.49	0.46	0.52	0.54
" " " " NC_4	1.07	1.06	1.11	1.22
" " " " IC_{5+}	1.15	0.88	1.17	1.14
EXTRACTION EFF. %	66.8*		64.5	61.0

*Estimated

By Edward G. Ragatz

FIG. 2. Results of four tests in a straight line chart plot.

steam consumption can be closely balanced with the reboiler-steam requirements of the fractionator.

The fractionator feed service, and the reflux services for both the stripping still and fractionator, are handled by simplex steam pumps. The exhaust from these reciprocating units, together with that of the boiler feed pump, supplies the stripping steam requirements of the still, which simultaneously disposes of the lubricating-oil contamination of the exhaust steam from these reciprocating units.

All water condensate from the stripping-still draw-offs and product-fractionator reboiler is collected and returned to the boiler-feed system. Available raw water is of bad quality, scarce, and expensive—hence the high degree of steam recovery thus achieved is of real monetary value at Cymric.

Cooling System. An aerial cooler employing two separate engine-driven fans is utilized for removing the high temperature heat from the still overhead—with the lower temperature heat from this stream, together with that of the lean-oil and product fractionator streams being removed at a conventional atmospheric type cooling tower. This cooling system arrangement effects an appreciable saving in expensive water consumption, and eliminates any high temperature stream being cooled in the cooling tower.

A steel-plate water-basin was installed on an elevated grade for the cooling tower for a further saving in over-all cooling system cost.

Cooling tower water is treated with sulfuric acid for pH control, a commercial algicide (Moberg) for algae control, and with chromates (Orocol) to control corrosion.

Boiler Plant. The plant is provided with three second-hand 104 hp, 250-hp oil-field type fire-box boilers. This boiler capacity is considerably in excess of that needed for the plant operation. In fact, one boiler can carry the plant load at well under normal rating, and one boiler constant fired as standby. The cost of the installed boiler plant was less than that of new equipment for the design load, thus providing a maximum of flexibility with a minimum of boiler maintenance.

An elevated atmospheric skimming tank is used for final separation of any light hydrocarbon contaminate of the reclaimed stripping-still and fractionator water condensate—with the streams from the stripping still draw-offs traversing coal-packed coagulators ahead of the skimming tank. Water from this skimming tank, plus treated make-up water, is introduced into a conventional atmospheric feed-water heater through which a very small "balancing" surplus of exhaust-steam from the plant is routed.

All boiler make-up water is Permutit treated.

General Plant Arrangement. To keep capital investment as low as possible, serious attention was paid to the design of an equipment layout that would be "compact, but not congested." This was achieved by the use of overhead pipe-ways, location of the tandem-operated pumps adjacent to and between the respective columns they served, use of three control boards placed on a common operating aisle adjacent to their respective units, and placement of interchangers and pumps on both sides of this com-

mon operating aisle, rather than using a single-sided operating front. Finally, though fire hazard requirements made it necessary to place the fired-heater and boilers some little distance from the operating plant area, the water treaters, feed-water heater, and boiler feed-water pumps were situated considerably closer to the main processing area.

Operator protection from the weather, and housing for an operator's desk and storage of operating and instrument records, is provided for by a small control-house fronting on the main operating aisle and centrally located thereto. This house has three sides of glass, which allows the operator to observe the main equipment while seated at his desk.

Product Storage and Disposal. Forty-two thousand gal of storage are provided for LPG and 38,000 gal for natural gasoline. A truck loading rack with both LPG and gasoline loading facilities is provided, as well as facilities for shipping gasoline by pipe line.

Operation. Two complete tests have been run on the Cymric plant, and two other tests on the absorption section only. Pertinent absorber data from these tests are shown in Table 1. These tests cover a variation in gas load from some 37,500 Mcf per day to 26,300 Mcf per day, with a corresponding variation in oil-gas ratio from some 7.60 gal per Mcf to 11.84 gal per Mcf. Propane absorption has ranged from 21.8 per cent to 44.4 per cent, and iso-butane absorption from 48.3 per cent to 88.1 per cent. An additional column has been added to Table 1 for comparison of the test operations with the expected operation when the rich-gas intake rate is reduced to 15,000 Mcf per day and the propane absorption increased to some 80 per cent.

Fig. 2 presents the results of the four plant tests in a straight-line chart plot. The steepness of the respective operating lines and their small differences in slope (representing an "extraction efficiency" spread of only 5 per cent in 61-66 per cent indicate excellent absorption performance for a wide range of loading. In fact, these particular tests represent the highest 400-500-lb absorber efficiencies of which we have any record.

Performance of the rectifier-reabsorber unit determined from the plant tests is shown in Table 2. High propane retentions, coupled with essentially complete deethanization, and at the same time maintaining a low temperature on the lean oil to the coolers, is the interesting feature of this table. Incidentally, as you can see, the "17.2 per cent" of lean oil over the reabsorber on the second test was a little too low to effect a full 90 per cent recovery of propane.

The stripping still operates with a heater outlet temperature of approximately 550 F. Plant lean oil is maintained at 180-185 molecular weight, with a 340 F Engler initial and a 30-40 millimeter water vapor pressure. Average gasoline end-point is 285 F, with an average 90 per cent point of 225 F. Fourteen-tenths pounds of stripping steam are used per gallon of lean oil.

TABLE 3. Absorption plant fuel and steam consumption.

Fuel gas	Test 3	Test 4
Oil heater, SMCF/day	224	320
Boilers, SMCF/day	208	177
Gas engines, SMCF/day	35	37
Total SMCF/day	467	534
Per cent of rich gas rate	1.61	2.03
Net heating value Btu/cu ft	1140	1146
Steam		
Process steam, lb/hr	4320	5000
Gaso. shipping pump, lb/hr	450	450
Total boiler load, lb/hr	4770	5450

Less steam could be used and has been used in the past, however, as all steam used is exhaust steam, and as the water condensate from the steam is recovered and returned to the boilers, no effort has been made to reduce the still steam consumption to a minimum.

The exceptionally low consumption of fuel by the units incorporated in this plant is aptly illustrated in Table 3. The total water circulated at the atmospheric water cooling tower averages 1300 gal per minute. Electric energy is purchased for plant lighting and to drive the LPG and standby shipping pumps only.

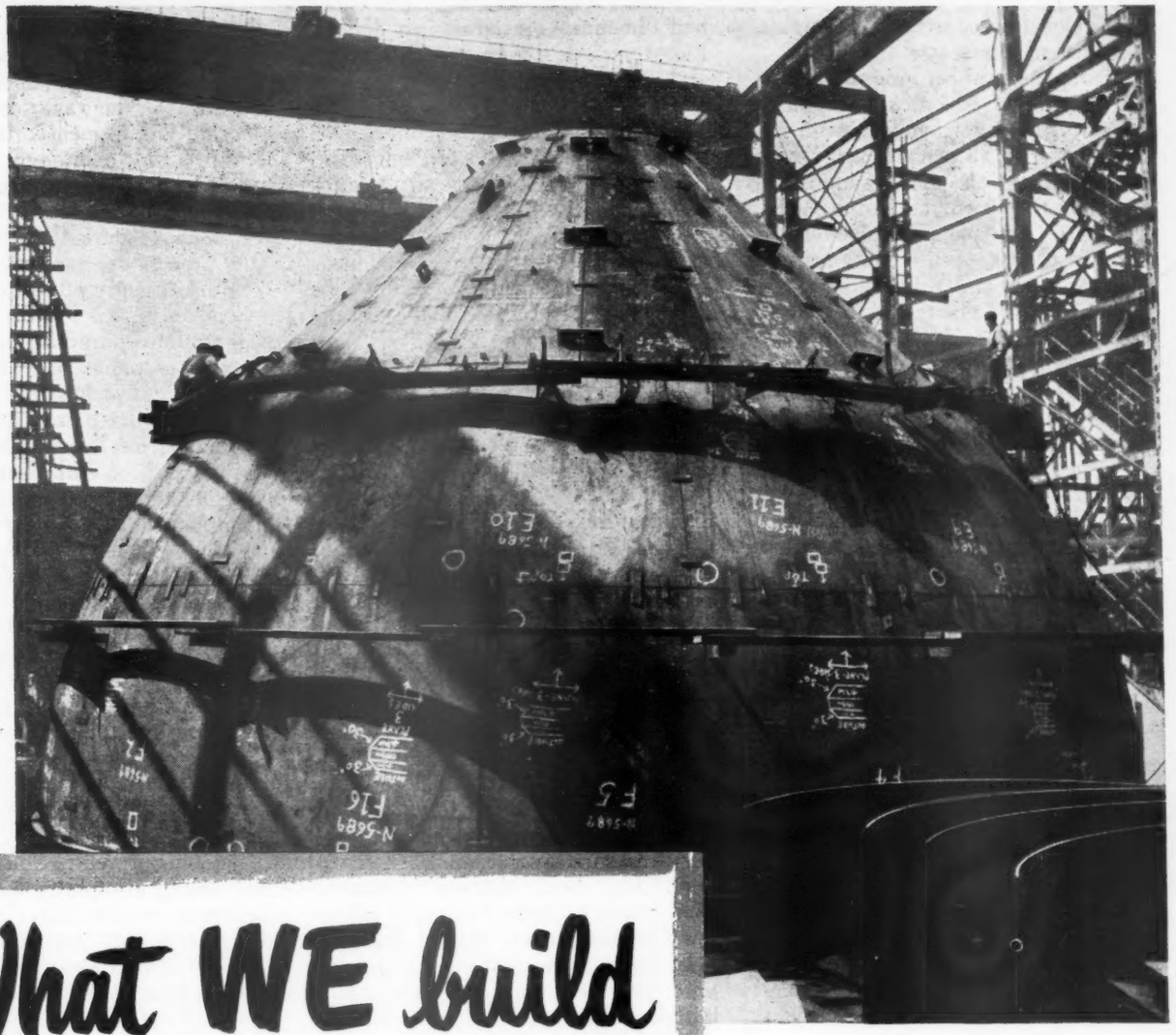
The Cymric plant performs smoothly and efficiently, and has fully met all our expectations. The plant was engineered and constructed by J. B. Gill Company and Edw. G. Ragatz, Associate, with the process design being furnished by Edw. G. Ragatz and the detailed engineering and construction performed by J. B. Gill Company. Patent applications are applied for by Edw. G. Ragatz on the rich-oil rectifier cycle employed. * * *

Chemical Plants on the Gulf Coast

At least 50 chemical plants, all of which employ as raw materials or as intermediates various products from the petroleum and natural gas industries, are operating or are building to operate on the Texas-Louisiana Gulf Coast, according to the most recent information available. The tremendous developments along these lines, by all odds the greatest chemical development this country or the world has ever seen, are traceable to a large number of factors, chief of which are the huge quantities of raw materials and/or intermediates available from these basic industries that have been developing along that coast during the last 30 years.

By common consent, the area known as the Gulf Coast area is defined as the belt from Lake Charles, Louisiana, on the east, and extending to Brownsville, Texas, immediately across the Rio Grande River from Old Mexico, and extending roughly 100 miles inland. Within this area are a great number of Firsts; first in the production of synthetic rubber, as witness the synthetic rubber, and the butadiene and styrene plants, at Port Neches, Texas; Neches Butane Products Company, largest producers of butadiene in the world; Cities Service Refining Company, Lake Charles, butadiene; Firestone Tire and Rubber Company, Lake Charles synthetic rubber, and General Tire and Rubber, Baytown, in connection with Humble's butadiene and styrene production. B. F. Goodrich, pioneer in synthetic rubber, for example Hycar, which was coming on the market as an independent product not associated with the Federal Government in 1940-41, has a branch company at Port Neches; similarly, Goodyear Synthetic Rubber Corporation is situated in the Houston area, for obvious purposes.

Among the more recent installations is that of Jefferson Chemical Company at Port Neches, a community interest of The Texas Company, with a combined refining plant total capacity of nearly 200,000 bbl of crude per day at Port Neches and at Port Arthur, a few miles away, near enough that plant cooling and processing water is sent in open conduits from the one plant to the other, 'cross country on the marshy, flat land where three



What WE build we build good

This is not a part of a ship or marine vessel, nor the nose of a huge torpedo. It is a section of a 55 foot diameter oil refining unit. It is being built in our plant where a large variety of similar equipment is built each year as regular products of this plant. Note the true shape and the accurate fits. Because of our vast facilities and long experience no job is too large and "what we build we build good."

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inches elevation constitutes a Heights, in suburban terms.

Among non-rubber organizations are Monsanto Chemical Company, makers of organic chemicals with hydrocarbons as raw materials, which was a victim of the terrible industrial explosion that occurred in the 1940s. Monsanto's new plant was demolished with great loss of life, only to rise from its ashes and rubble to become again one of the greatest of the Southwest's chemical manufacturers. Most of these companies are adjuncts to refineries, where large quantities of raw hydrocarbons, especially the highly reactive olefins, are available from cracking units, etc., for purchase. They are then converted to all types of important chemicals, from which are manufactured the greatest list of industrial and commercial products ever known to man.

The pioneers in all this assembly of chemical manufacturing capacity must not be overlooked. These include among many others The Celanese Corporation, at Bishop, vicinity of Corpus Christi and the world-famous King Cattle Ranch, making aldehydes, alcohols, ketones, and other oxygenated organic chemicals, "breaking trail" on many of the serious problems in that extensive and rapidly growing field. Shell Chemical Company at Deer Park (Houston Ship Channel area) was the first to manufacture synthetic glycerin from olefinic gases such as propylene, by a process still the wonder of the manufacturing chemists. Carbide and Carbon Chemicals moved in next door to Pan American Refining at Texas City, and began making a host of the oxygenated organics for which that company is justly famous. DuPont needed a plant for making "nylon salt" base for Milady's stockings, swim suits, and numberless other products, so it went to Orange, long-time center for gas, petroleum, and forest products, and is now making more nylon base material there than is made at any point in the world.

Allyl alcohol is one of the "stormy petrels" of the chemical manufacturing world, and not until Shell worked out its synthesis along with that of glycerin could its production be depended on. Now it may be had for any chemical purpose.

The list of Gulf Coast-manufactured chemicals is as wide as the organic chemical industry: "Carbon tet." available from Dow at Freeport, home of the sulfur industry; butyl alcohols, from Celanese at Bishop; benzene, toluene, other aromatics from Humble at Houston, Magnolia at Beaumont, and from several other plants if and when needed for industrial or military purposes. Diethylene glycol, which is used as an antifreeze in huge quantities and as a chemical intermediate for dyes, solvents, plastics, comes from Carbide, Dow, and Jefferson Chemical. Even drying oils, that field reserved since the beginning of time for the plant and animal oil kingdom, are produced in industrial quantities by, not a castor bean or flaxseed unit, but by Pan American Refining at Texas City.

Shell, Carbide, Celanese, and many others make butyl alcohols without waiting for the vagaries of the First World War ferment principle; make "grain" or "drinking" alcohol that never had the slightest relationship to wheat, corn, rye, barley, or brewer's yeast, more pure than the fermentation process can possibly produce.

More recently other lines are being extended to this Gulf Coast region. Lubrizol Corporation, in spite of its lugubrious name, one of the greatest suppliers of additives and similar agents for the petroleum and chemical industries, has bought a plant site on the Houston ship channel where it is understood the company expects to manufacture its primary products in an area near the producers of its raw materials and the consumers of its finished products. General Aniline and Film Corporation, world-known for its production of photographic chemicals and equipment, and for chemicals in general, is understood to have completed an intensive survey of the Gulf Coast's possibilities as a manufacturing site, and has plans for future expansion when conditions make such action feasible.

Below is presented a list of the various chemical companies and their locations, to show how this phenomenal growth has extended. In a later issue of *The Petroleum Engineer* a more detailed survey of all these activities will be made and reported, to give a more comprehensive view of these all-important developments. * *

Company Name	*Location*	*Main Products*
Air Reduction	Magnolia, Houston	Oxygen, et al
Aluminum Co. of America	Port Lavaca	All metal, etc.
American Smelting and Refining	Corpus Christi	Steel, metals
Armour Fertilizer Works	Houston	Plant fertilizers
Best Fertilizers	Houston	Plant fertilizers
Carbide and Carbon Chemicals	Texas City	Oxygenated organic chemicals
Carthage Hydrocol, Inc.	Brownsville	Synthetic fuels, hydrocarbons
Celanese Corporation	Bishop	Oxygenated organic chemicals
Champion Paper and Fiber	Pasadena (Houston)	Paper and products
Cities Service Refining	Lake Charles, Louisiana	Butadiene, etc.
Clorox Chemical Company	Houston	Chlorinated organic chemicals
Columbian Carbon Company	Corpus Christi	Carbon and chemical products
Consolidated Chemical Industries	Houston	Ammonium sulfate, fertilizers
Crosby Chemicals	De Ridder, Louisiana	Camphene, dipentene, etc. (forest products)
Diamond Alkali	Pasadena (Houston)	Organic and inorganic chemicals
Douglas Sulfur	Houston	Sulfur
Dow Chemical	Freeport	Oxygenated organics
E. I. duPont de Nemours	Orange, LaPorte, Victoria	Nylon salt, etc.
Finney Chemical Company	Houston	Ammonium sulfate
Firestone Tire and Rubber	Lake Charles	Synthetic rubber
General Tire and Rubber	Lake Charles	Synthetic rubber
B. F. Goodrich Chemical	Port Neches	Synthetic rubber
Goodyear Synthetic Rubber	Houston	Synthetic rubber
Great Lakes Carbon	Port Arthur	Carbon and products
Houston Oxygen	Houston	Oxygen, hydrocarbon products, air products
Humble Oil and Refining	Baytown	Aromatics, butadiene, styrene
Jefferson Chemical	Port Neches	Organic chemicals
Kelly, Weber and Co., Inc.	Lake Charles	Fertilizers
Linde Air Products	Houston	Air products
Liquid Carbonic	Houston	Carbon dioxide, air products
McCarthy Chemical	Houston and Winnie	Organic chemicals
Mathieson Chemical	Beaumont, Lake Charles, Houston, Port Arthur	Organic and inorganic chemicals
Merichem Company	Houston	Petroleum waxes, etc.
Monsanto Chemical	Texas City	Organic chemicals
National Cylinder Gas	Houston	Oxygen, air products
Natural Gas Odorizing	Houston	Odorants
Neches Butane Products	Port Neches	Butadiene
Nyotex Chemicals, Inc.	Houston	$AlCl_3$, HF, etc.
Pan American Refining Corporation	Texas City	Aromatics, solvents
Phillips Chemical Company	Pasadena	Organic chemicals, solvents
Pontiac Refining	Corpus Christi	Ethylene oxide, glycol, butadiene, etc.
Rohm and Hass	Pasadena	Organic chemicals
Sheffield Steel	Houston	Pig iron, steel, etc.
Shell Chemical	Houston	Allyl alcohol, glycerin, organics
Southern Alkali	Corpus Christi, Lake Charles	Inorganic chemicals, acids
Stauffer Chemical	Freeport	Sulfur, inorganics
Tin Processing Corp.	Texas City	Tin metal
United Carbon	Corpus Christi, et al	Carbon black, etc.
Visco Products	Sugarland	
Projected:		
The Lubrizol Corp.	Houston	Lubricant and specialty additives

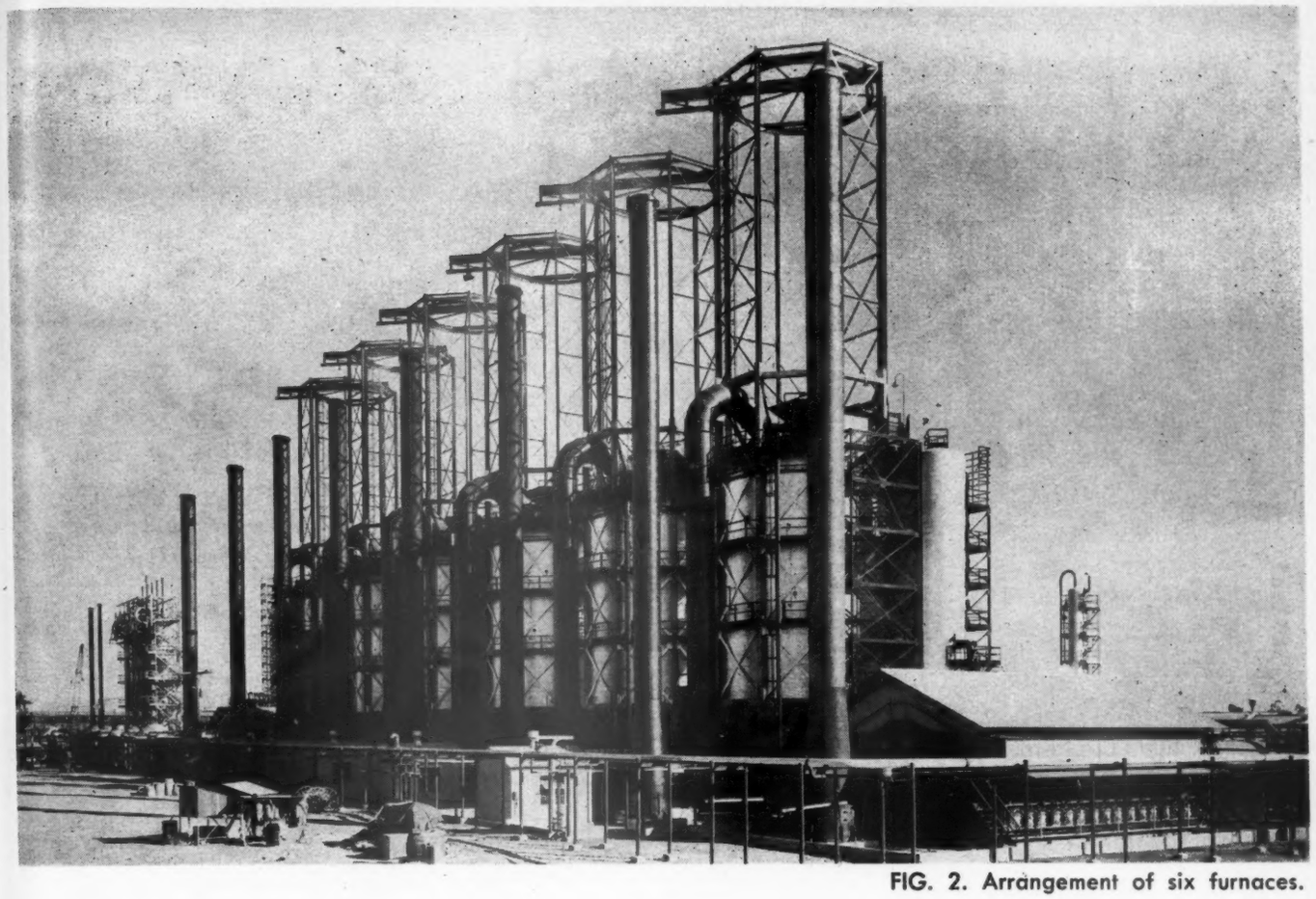

FIG. 2. Arrangement of six furnaces.

Cylindrical Furnaces for Petroleum Industry*

A Survey of the Art of Furnace Designing, Beginning With the de Florez Furnace, Showing the Details and Adaptability of Different Designs.

O. F. CAMPBELL†

THE use of cylindrical furnaces for the petroleum industry has steadily increased since the advent of the original cylindrical furnace invented by Luis de Florez for refinery use some 20 years ago. This type of furnace has not been universally adopted primarily because of a lack of understanding of its capabilities. The purposes of this paper are to describe, discuss, show designs of, provide, and comment upon some operating data for de Florez, Iso-Flow, and other types of cylindrical furnaces.

*Contributed by the Fuels Division for presentation at the semi-annual meeting, San Francisco, California, June 27-30, 1949, of The American Society of Mechanical Engineers.

†Sinclair Refining Company, East Chicago, Indiana.

The cylindrical furnace has been used successfully for many duties such as; crude topping, heating reduced crude for vacuum distillation to produce lubricating oils and asphalts, light and heavy gas oil cracking, evaporating and superheating oil vapors for the Houdry and Thermafor catalytic cracking processes, heating up lube oils and solvents, heating up fat absorption oil for casing head production, high and low temperatures steam superheating, heating asphalts for loading purposes, domestic heating, and many other uses. The future offers still greater development and use because of its simplicity and flexibility it can be built for substantially any duty, capacity, or efficiency. Its inherent design automatically provides more uniform heat distribution and absorption, low maintenance, low radiation losses, ease of cleaning, adaptability to heat recovery equipment, less fire hazards, low space requirements, etc.

de Florez Furnaces

The original design of the de Florez furnace was a down fired furnace using cold forced air, a bottom convection section, and a natural draft stack. Subsequent installations had many variations. Some were fired from the bottom with a convection section on top using neither forced nor

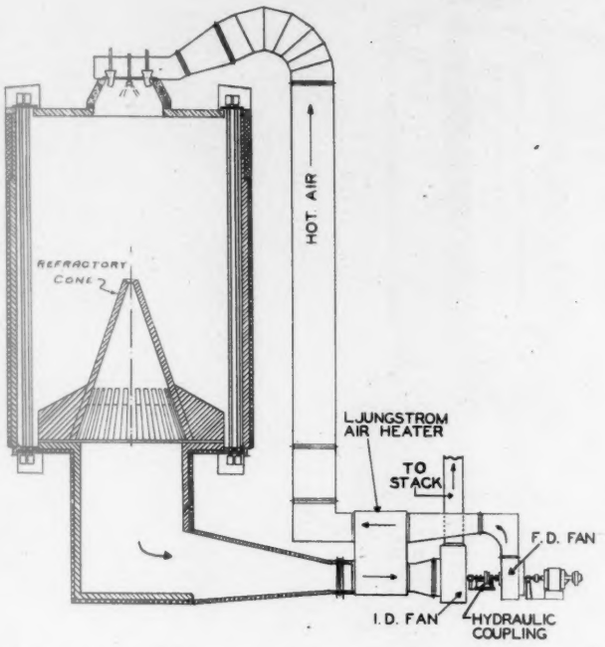

FIG. 1. Downdraft of de Florenz furnace equipped with Ljungstrom air heater.

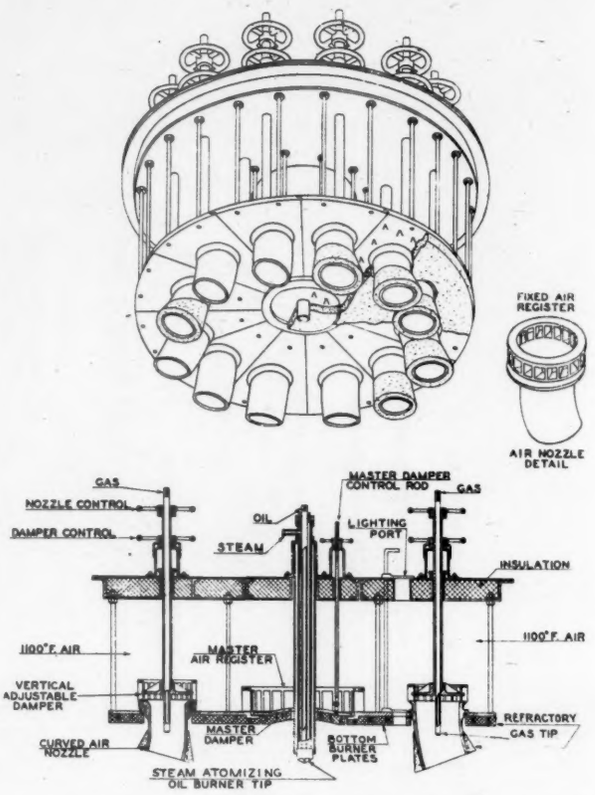

FIG. 3. Special burner used with downdraft de Florez furnaces and Ljungstrom air heaters.

induced draft. Some were bottom fired using a convection section and air heater on top and a forced draft fan. The up fired units normally do not have induced draft. The air heaters on top of the furnace were of the tubular or plate type to keep the draft drop to a minimum to avoid the use of a taller stack. The furnace and air heater being vertical, produced a chimney effect and actually served as part of the stack.

The most successful design of the de Florez furnace that has been adopted as a standard by the Sinclair Refining Company consists of (a) top-supported all radiant oil heating tubes, (b) down firing with a specially designed directional flame control oil and gas fired burner, (c) a vertical refractory cone resting on the bottom of the furnace for better heat distribution, (d) a high temperature Ljungstrom air heater, (e) forced and induced draft fans motor driven, (f) and a short self supporting steel stack. This general design is shown by Fig. 1. An arrangement of six of the furnaces is shown by Fig. 2.

The details of the directional flame control burner is shown by Fig. 3. This burner handles refinery gas, natural gas, or heavy fuel oil. The fuel oil burner is of the steam atomizing type. This directional flame control burner can provide the desired flame shape. The flame can be made long and narrow or short and bushy as desired. The flame can be shifted from one side of the furnace to the other to give the desired heating curve. Each 7-in. ID air nozzle can supply enough air to burn between 10 and 15 million Btu per hour.

The de Florez furnace is very adaptable to substantially any design of tube arrangement to give the required oil heating curve. For thermal cracking it is desirous to heat the oil to be cracked up to a predetermined temperature as rapidly as possible and then to maintain that temperature to provide time for cracking or "soaking time." For crude topping and for heating up gas oil for catalytic cracking it is advantageous to have very little or no thermal cracking and no "soaking time." In practically all oil heating problems by direct firing the oil is forced through the tubes, in series flow although there may be several heating coils in the same furnace. To reduce pressure drop through the oil heating coils it is sometimes desirable to parallel the oil tubes at points of vaporization. This is normally done on vacuum distillation units or where it is necessary to vaporize the oil and then superheat the vapors. Where only superheating of vapors is required there may be several parallel flows.

To simply illustrate the flexibility of design of the cylindrical furnace no more than two heating coils in any one furnace has been selected. In the majority of cases the two coil furnace is the more practical from design and operating standpoints. Figs. 4 through 9 illustrate some of the tube arrangements used and the effect of these tube arrangements on the shape of the oil heating curve. From the various tube arrangements and oil heating curves it can readily be seen that almost any kind of a heating curve can be obtained. If a furnace is designed for thermal cracking it is only necessary to reverse the oil flow to provide an oil heating furnace without cracking.

Fig. 4 shows a split coil arrangement with the oil entering the back row of tubes going half the distance around the furnace and then returning through the inside row of tubes. All return bends are the same size to simplify design. This furnace was designed for heating with no "soaking time" and the slope of the heating

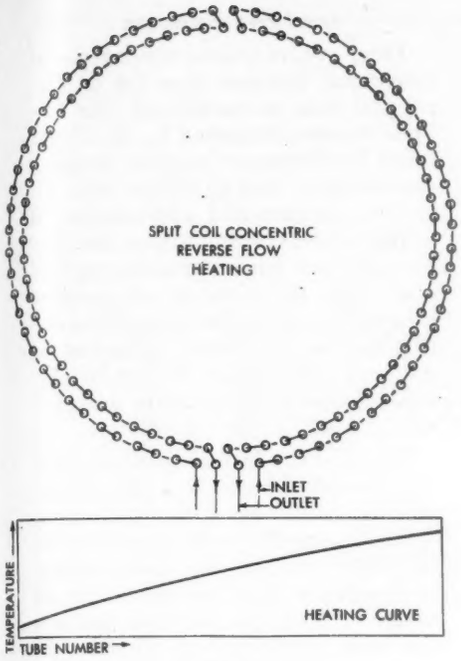

FIG. 4

curve shows no "soaking time." The split coil was used to reduce pressure drop.

Fig. 5 shows another type of split coil staggered flow arrangement for oil heating duty only. The oil heating curve of this furnace was very desirable because reduced crude of high salt content was being heated and the salt deposited near the inlet tubes. The flame control burner was used to direct the flame toward the outlet tubes. Tube shields were also used to keep too much heat from being absorbed by the first four inlet tubes where the salt deposited.

Fig. 6 shows a split coil staggered flow for a vacuum distillation unit. The tube arrangement is the same general layout as shown by Fig. 5 except that the last two tubes in each coil are parallel flow. Any number of tubes can be paralleled or tube size may be increased.

Fig. 7 shows tube arrangement for a thermal cracking still. The oil flows through a split coil concentric reverse flow with the oil passing through the inside row first to be heated up to cracking temperature and then through the second and back row for "soaking." The shape of the heating curve indicates satisfactory conditions for cracking. The split coil provides lower pressure drop and satisfactory soaking time.

Fig. 8 shows a single coil of the staggered concentric reverse flow tube layout for a thermal cracking still. This tube arrangement provides very good thermal cracking conditions but has a rather high pressure drop and represents somewhat of an extreme soaking condition not necessarily required.

Fig. 9 shows a thermal cracking still equipped with two furnaces. The first furnace is a split staggered flow for heating the oil up to a cracking temperature. The second furnace is a split coil concentric reverse flow for soaking. The heating curve of this arrangement can be held almost any shape to provide optimum cracking. The two furnace hook-up has the disadvantage of higher first cost per barrel of gasoline produced as compared with two furnaces each designed as shown by Fig. 7.

With proper understanding of tube arrangement, flame control for heat distribution, refractory cone for better heat distribution, and highly preheated air, the de Florez furnace can be designed for maximum heat absorption and maximum efficiency regardless of inlet or outlet oil temperatures, for any kind of service required. Maintenance is low because the oil tubes protect the refractory walls. Some of these de Florez furnaces have been in use about 20 years without any maintenance to refractory walls or top arch. Burner throats are the major source of repairs and some of the throats are over 10 years old with-

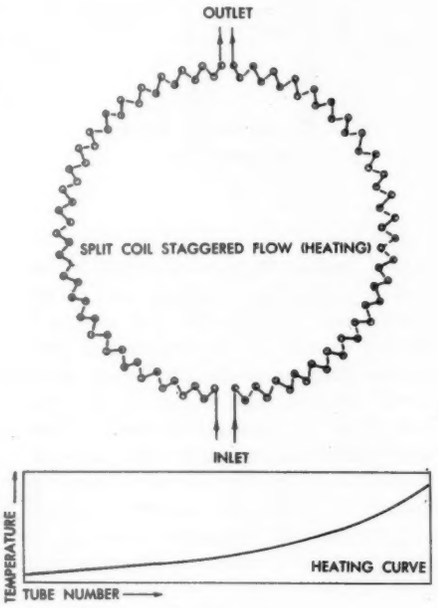

FIG. 5

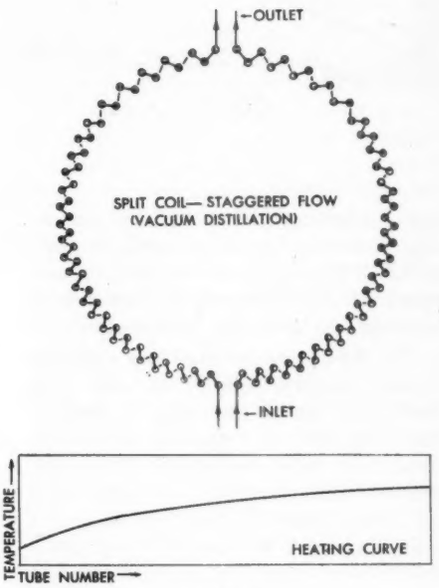

FIG. 6

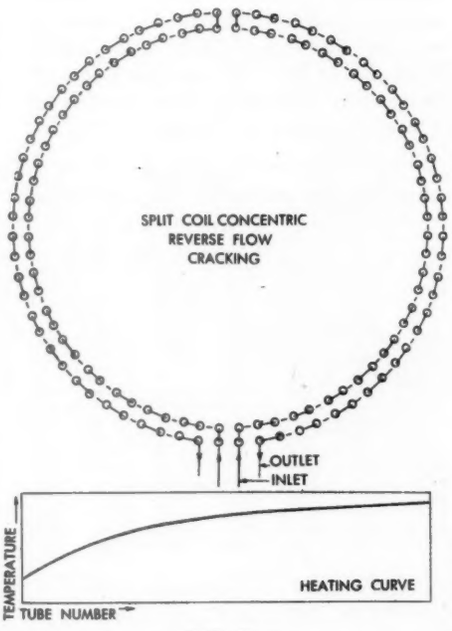

FIG. 7

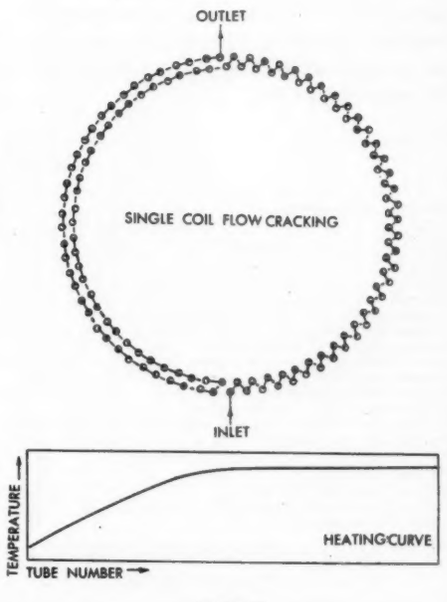

FIG. 8

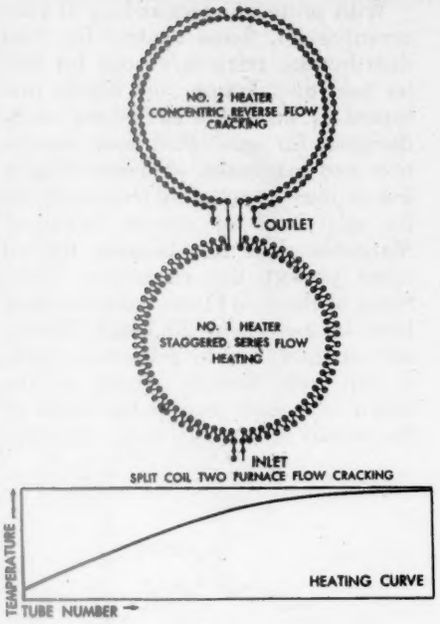

FIG. 9

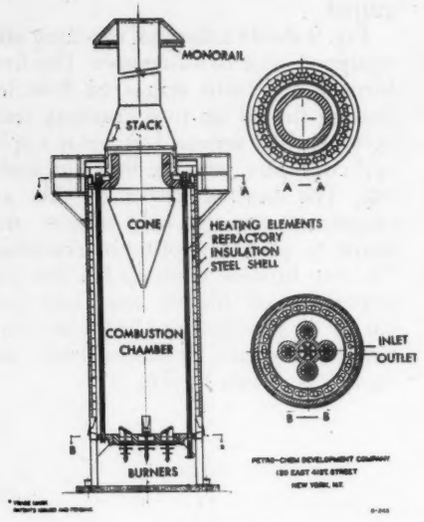

FIG. 10. Iso-Flow furnace, radiant type.

out replacing. Some thermal cracking furnaces have operated as high as 120,000 hours without tube replacement attributed largely to proper heat distribution and tube arrangement.

The de Florez furnace has some desirable features worthy of note. Cast iron tube sheets are used to support the tubes and no expensive alloys are used for tube supports. With suspended tubes any tube warpage is of no consequence. When burning fuel oil with high ash content the accumulation of ash does not plug off any flue gas passage or appear to interfere with heat transfer. As the ash builds up on the tubes the furnace temperature increases enough to obtain the desired heat transfer without materially increasing the flue gas temperatures entering the air heater. All tubes may be readily observed. Thermocouples may be placed at will and hot tubes can be seen with ease.

The use of the Ljungstrom type air heater makes it uneconomical to install a convection section as the air heater can do a better job cheaper. The air heater can be designed to give an efficiency equivalent to boiler practice if desired. The use of highly preheated air increases the rate of heat absorption by radiation and will decrease the number of oil tubes required for a definite quantity of heat to be absorbed. In some cases where expensive alloy tubes are required for sour crude operations the reduction in cost of oil tubes will offset cost of an air heater, fans, and their drivers.

The fuel prices of the past few years have compelled the installation of air heaters or other heat recovery equipment to reduce fuel costs in order to survive in this highly competitive field. Table No. 1 gives some standard every day operating data for the de Florez furnaces as outlined above.

Iso-Flow Furnaces

There are, of course, other types of cylindrical furnaces than the de Florez that must be considered. The Iso-Flow furnace furnished by the Petro-Chem Development Company deserves consideration and credit for their ingenious designs and applications. It is the writer's opinion that the Iso-Flow furnace has its greatest application where the mean oil temperature is low. There are no reasons, however, why the Iso-Flow furnace cannot be designed with an air heater to give high efficiency and in many instances this is done.

The Iso-Flow furnace is a very popular furnace because it is very adaptable for small heat duties, it is cheap to build, requires small ground space, has high efficiency for low temperature stocks without the use of an air heater or fans. The Iso-Flow furnace has many applications. It fills the needs of the smaller furnace field very efficiently and economically. The writer is only familiar and experienced with Iso-Flow furnaces up to 50 million Btu absorption per hour and for relatively low average temperature of stocks to be heated, and shall limit illustrations and comments accordingly.

The original design of the "Iso-Flow" furnace consisted of a vertical cylindrical shell of light sheet steel, insulated on the inside with insulating refractory or firebrick. Inside this insulated cylinder bottom supported vertical tubes were erected adjacent to the wall, burners were placed in a refractory well placed at the bottom of the furnace, and the flue gases escaped through a stack placed on top of the furnace. There was suspended in the top of the furnace an alloy or refractory cone to radiate heat to the upper part of the tubes and to deflect the flue gases around the tubes in the upper part of the furnace. There have

TABLE 1. Summary of operating data on de Florez heaters.

Combustion data survey	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fuel used	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas	R. Gas
Per cent CO_2 entering air heater	10.4	10.4	10.7	12.0	10.2	11.4	11.4	11.8	11.0	10.8	11.8	10.4	11.8	11.3	12.0	11.1
Per cent O_2 entering air heater	4.6	4.8	3.2	2.0	4.1	3.1	3.2	1.8	3.4	3.8	2.0	3.5	1.5	2.5	.9	2.3
Per cent CO_2 leaving air heater	9.0	9.0	9.1	10.0	8.8	9.6	9.2	9.8	8.7	9.0	10.0	9.0	10.3	10.1	10.8	9.9
Per cent O_2 leaving air heater	6.9	6.8	5.9	5.3	6.4	5.8	5.9	5.8	7.4	6.9	5.3	5.7	4.0	4.4	2.6	4.2
Flue-gas temperature (F) into air heater	1200	1117	1010	1210	990	1190	980	960	1025	980	1035	910	888	970	1205	1170
Flue-gas temperature (F) out of air heater	450	521	470	440	465	465	365	355	405	390	380	390	400	435	493	510
Air temperature (F) into air heater	22	80	60	33	60	33	26	62	56	10	22	101	100	100	99	63
Air temperature (F) out of air heater	810	796	730	830	705	835	725	780	855	815	850	755	755	812	975	980
Air pressure ("H_2O) into air heater	4.9	5.0	4.20	6.75	3.8	7.75	4.4	5.0	6.25	5.5	6.6	5.2	4.9	6.7	7.6	9.7
Air pressure ("H_2O) out of air heater	3.5	3.0	2.6	5.5	2.4	5.5	3.0	4.0	4.75	4.25	5.5	3.1	3.0	4.1	4.7	6.4
Flue-gas draft ("H_2O) into air heater	.85	.80	.75	.75	.68	.89	.80	.90	1.10	.80	.95	.80	.80	1.0	1.0	1.40
Flue-gas draft ("H_2O) out of air heater	1.60	2.20	2.5	1.88	2.3	2.50	2.2	2.0	2.2	2.4	2.9	3.4	3.8	4.5	5.0	6.60
Per cent air heater leakage[1]	15.6	15.5	18.0	20.0	16.0	17.7	23.9	20.0	26.4	20.0	18.0	13.0	13.0	10.0	9.00	10.0
Per cent stack loss	19.2	19.5	19.8	17.5	19.9	18.0	16.1	15.5	17.8	16.5	15.8	16.1	16.4	16.6	17.7	19.5
Per cent efficiency[2]	75.8	75.5	75.2	77.5	75.1	77.0	78.9	79.5	77.2	78.1	79.2	78.9	78.6	78.4	77.3	75.2
Million Btu liberated in furnace	49.5	52.1	56.3	58.0	59.4	70.0	71.68	73.6	84.7	89.95	91.66	93.3	102.0	117.0	127.0	137.9
Million Btu absorbed by oil tubes	37.52	39.33	42.34	44.59	44.61	53.9	56.55	58.51	65.39	70.25	72.59	73.61	80.17	91.73	98.17	103.7
Length of elements	27"	27"	27"	27"	27"	27"	36"	48"	48"	48"	48"	48"	48"	48"	48"	48"

$$\text{Per cent leakage} = \frac{(\%\ CO_2\ \text{in}) - (\%\ CO_2\ \text{out})}{(\%\ CO_2\ \text{out})} \times 100.$$

[1] Per cent efficiency = 100% — (stack loss + 5% radiation loss).

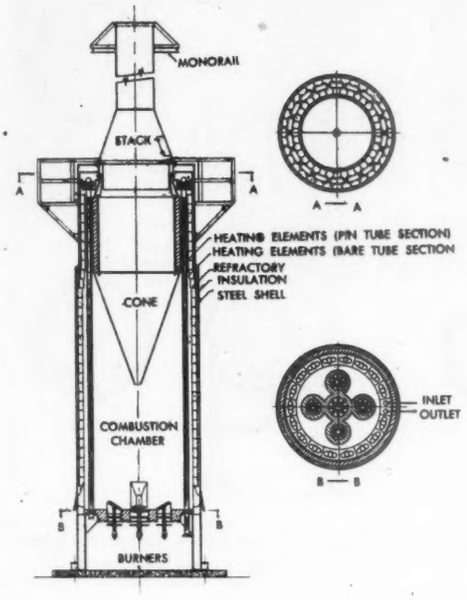

FIG. 11. Iso-Flow furnace, radiant-convection type.

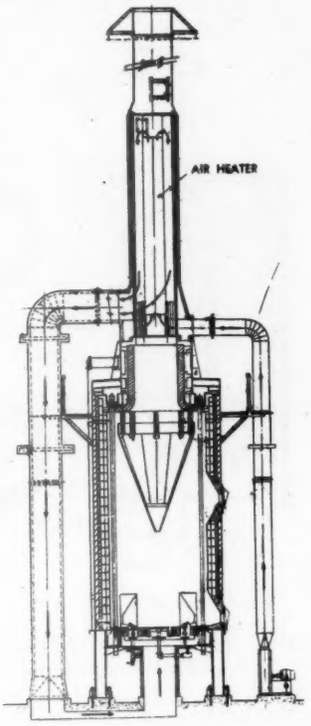

FIG. 12. Iso-Flow furnace, radiant type with air heater.

been many improvements and innovations over the original design.

Fig. 10 illustrates the radiant type Iso-Flow furnace. The original firing well at bottom of furnace has been eliminated and this furnace is equipped with five John Zink burners in the bottom of the furnace. The four outside burners are so designed as to give direction to the fire and distribution of heat to the tubes. The tubes are supported from the bottom and are set in a single row. The bottom of the stack is equipped with a draft hood somewhat similar to a draft hood on a domestic gas furnace. The stack is equipped with a circular mono rail for tube removal and cleaning purposes. The upper throat of the furnace is made of refractory. No supporting structural steel is employed thereby making a less costly installation. The efficiency of this type of furnace is dependent upon the excess air in the furnace, average temperature of stock inside the tubes, and the heat absorption rate. This type of furnace is usually used where low cost of installation is required and low priced fuel is available.

Fig. 11 illustrates the radiant-convection type of Iso-Flow furnace. The design of the radiant-convection type is substantially the same as the radiant type except that the radiant cone is suspended from a hollow cylinder inserted at the top of the furnace. The tubes between the two concentric hollow cylinders are equipped with longitudinal fins and constitutes the convection section. The radiant convection types are usually used where fuel economy is desirable and low average oil temperatures are encountered. The fins or extended surface increases the heat absorption by the tubes in the convection section to substantially that of the radiant section and at the same time increases the efficiency. With an average temperature of approximately 450 F of oil in the tubes, the efficiency of the radiant-convection type for a heat absorption rate based on tube surface only of 8000 to 10,000 Btu per square ft per hour is approximately 70-72 per cent based on the gross heating value of the fuel.

Fig. 12 illustrates an Iso-Flow furnace of the radiant type equipped with an air heater to provide greater economy and to obtain greater heat absorption rate per square foot of tube surface.

The air heater is of the tubular design and is inserted in the stack and forms an integral part of the stack. The stack forms the outer shell of the air heater. Inasmuch as the air heater is in the vertical stack the chimney action of the flue gases in the stack overcomes the major part of the draft loss of the flue gases passing through the air heater and as a result no induced draft fan is required. The forced air is supplied by a forced draft fan, which delivers the air to the air heater, and the cold air first passes over the bottom tube sheet to keep it as cold as possible and then through a circular duct placed in the center of the air heater to the top of the air heater where the air then flows counter current to the flue gases passing through the air heater. The hot air leaving the air heater flows downward

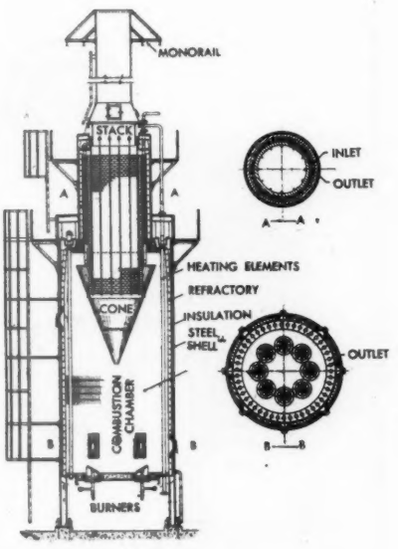

FIG. 13. Iso-Flow furnace with separate convection section.

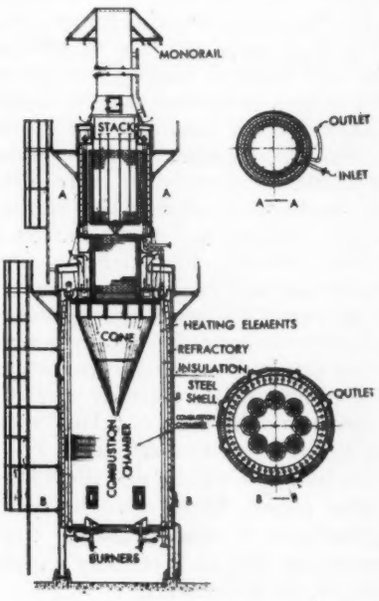

FIG. 14. Iso-Flow furnace with separate convection section.

through an insulated duct to the windbox at the bottom of the furnace. The efficiency of this type of furnace can be as desired and will depend upon the price of fuel. If fuel prices are high a large heater can be used and if fuel prices are low a smaller air heater may be used.

Figs. 13 and 14 show designs of Iso-Flow furnaces equipped with separate convection surfaces but without air heaters. Air heaters can be added to furnaces of this design if greater efficiency is desired. It is the writer's opinion that the more economical arrangement would be a radiant-convection furnace for high average oil temperatures as shown by Fig. 11 supplemented by air heater instead of arrangement of surfaces as shown by Figs. 13 and 14. Fig. 13 illustrates a design of a separate convection section where services are such that it is unnecessary to internally clean the convection section. Fig. 14 illustrates a design of a separate convection section where services are such that the convection section must be cleaned internally.

Fig. 15 shows an Iso-Flow economizer of the auxiliary fired type, which may have many possibilities. This unique design allows control of the temperature of the products heated and at the same time effects a fuel saving by recovering heat from the hot flue gases of existing inefficient units. For example, a box type cracking still having a radiant furnace and a down draft convection section may be already installed. The charging stock to this furnace may be as high as 700 F and a stack temperature may be as high as 900 to 1000 F. The excess air in the flue gases from this furnace may be as high as 75 per cent to 100 per cent and there is usually enough excess oxygen in the flue gases to supply oxygen for the auxiliary fire of the Iso-Flow economizer and no added air would be required. If more selective cracking, or another heating furnace is desired, and there usually is in any refinery, the auxiliary fired economizer may be justifiable. In fact an air heater on top of the separately fired economizer could supply hot air to the original cracking furnace and as a result greater capacity and efficiency could be effected. This separately fired economizer may be a steam boiler as will be described later in this paper. There may be many applications to this separately fired economizer and each refinery's problems will be different.

Fig. 16 illustrates an Iso-Flow bent tube parallel flow superheater. This type of superheater is usually used for superheating steam where fuel economy is not essential, total heat absorbed is quite low, and where first low cost is important. There are a large number of furnaces of this type and they are used to superheat steam from field boilers that are not designed with superheaters.

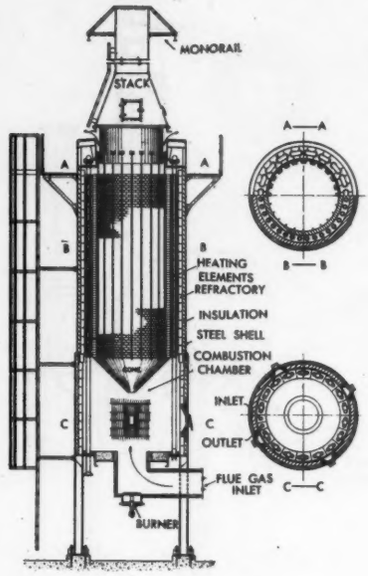

FIG. 15. Iso-Flow economizer, auxiliary fired type.

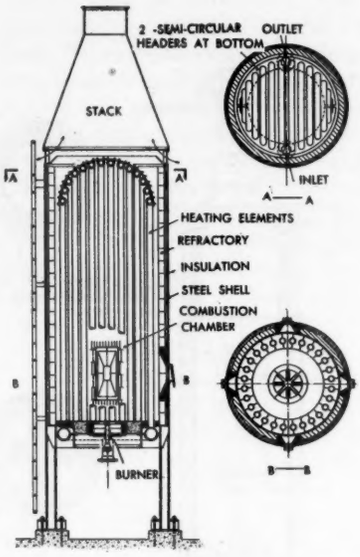

FIG. 16. Iso-Flow furnace, bent tube superheater.

Figs. 17 and 18 illustrate inverted bent tube series and parallel flow radiant type Iso-Flow furnaces of low capacity where low first cost is paramount and efficiency unimportant.

Fig. 19 illustrates the design of the extended convection surface. The longitudinal fins are welded to the tubes by automatic welding equipment and as a result this extended surface is not too expensive. The design of this extended surface is such that the heat absorption per square foot of tube surface is approximately the same in both the radiant and convection sections. Where the average temperature of the stock in the tubes does not exceed approximately 550 F and with the proper design of radiant and con-

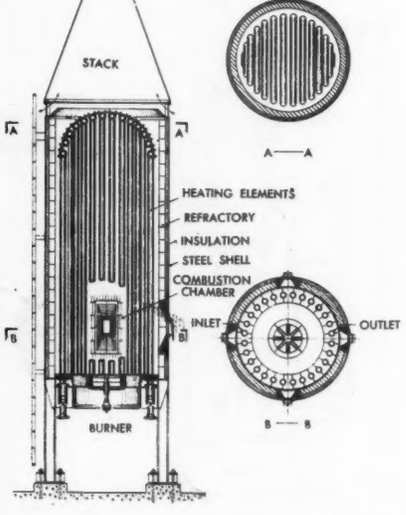

FIG. 17. Iso-Flow furnace, bent tube type.

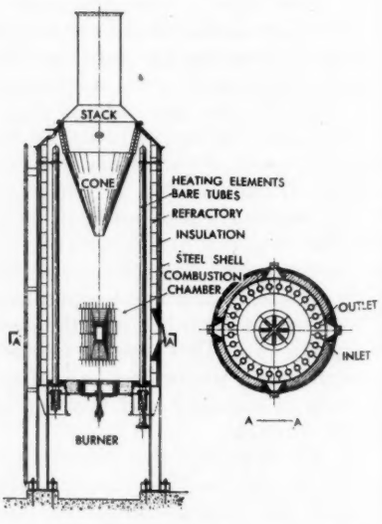

FIG. 18. Iso-Flow furnace, radiant type. (Inverted U).

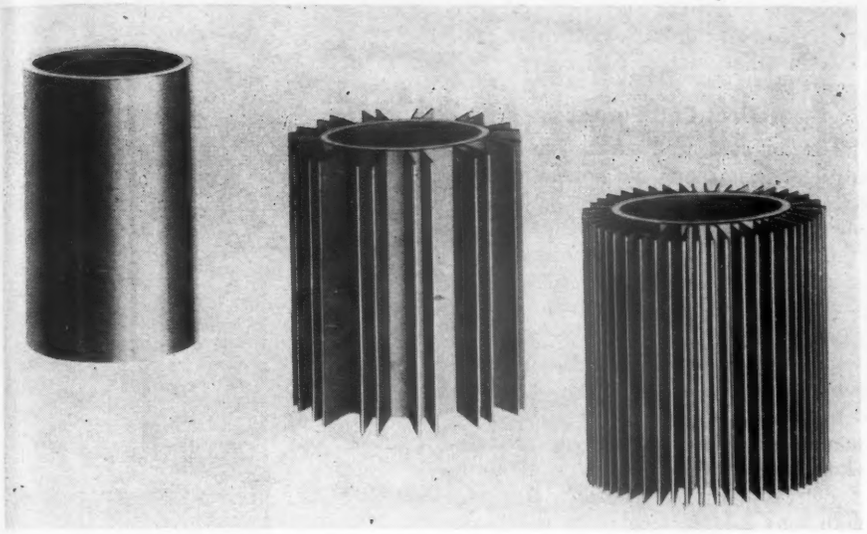

FIG. 19. Illustration of extended surface for convection section.

TABLE 2.
Petro-Chem furnace design data for heating oil-phenol mixture.**

Number of tubes	44
Size of tubes	5 in by 4 in
Radiant surface	1,579 sq ft
Convection surface	2,487 sq ft
Total surface	4,066 sq ft
Tube circle diameter	10 ft 6 in
Inside furnace diameter	11 ft 9 in
Height of furnace	38 ft 3½ in
Height of stack	31 ft 0 in
Total height of furnace and stack	68 ft 3½ in
Combustion volume	2,524 cu ft
Number of burners	9
Type of burners	John Zink (Directional-spider premix)
Length of convection section	7 ft
Length of radiant section	27 ft 4½ in
Btu released per hour (normal)	21,200,000
Btu absorbed per sq ft radiant section	8,800
Btu absorbed per sq ft total surface	4,070
Flue gas temperature convection inlet	1,000 F
Flue gas temperature convection outlet	680 F
Excess air	40 per cent
Temperature oil-phenol mixture into furnace	420 F
Temperature oil-phenol mixture out of furnace	560 F

** Sinclair Refining Company — Houston, Texas

vection sections it is usually uneconomical to install an air heater or other heat recovery equipment.

Operating and Design Data

In verification of the performance of an Iso-Flow radiant-convection type furnace three tests were made on a furnace heating a mixture of oil-phenol at the Sinclair Refining Company's plant at Houston, Texas. Table No. 2 shows some pertinent design data. Table No. 3 shows a tabulation of the test data. It is apparent from the test data that the unit did not operate under the same conditions as designed, which is the usual practice for oil refinery equipment. The flue gas temperatures were higher leaving the convection section than design but the excess air was less. The same may be said for flue gas temperatures for the convection section inlet. Some interesting items of the tests revealed that the furnace could be operated at 35 per cent above normal design with an efficiency of 73 per cent based on the gross heating value of the fuel, the radiation loss was low, the lowest excess air during normal operation that could be obtained was approximately 15 per cent in the furnace and 22 per cent leaving convection section indicating a better burner desirable, furnace temperatures were higher than expected, control of outlet Oil-Phenol mixture temperatures easily accomplished, and very uniform with split coil flow, and no operating difficulties.

"Iso-Flow" Boiler Design

The application of the cylindrical furnace to a steam boiler is another innovation of the Petro-Chem Development Company. One cylindrical furnace boiler has been in operation for several years and consists of a horizontal drum situated above the furnace into which the furnace tubes deliver the water-steam mixture and is quite similar to a conventional boiler design. The furnace tubes are supplied with water by outside downcomers from the boiler drum. It is understood that this boiler operates satisfactorily well above design capacity.

Fig. 20 illustrates a new and novel boiler design. This novel design includes a vertical steam drum instead

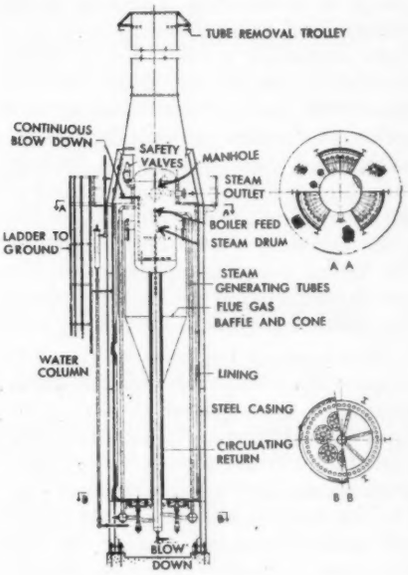

FIG. 20. Iso-Flow furnace, steam generator.

TABLE 3. Test data on Petro-Chem furnace for heating oil-phenol mixture.**

	Test No. 1	Test No. 2	Test No. 3
Charge to furnace B/D	4,950	7,290	6,660
Temperature charge in F	432	432	435
Temperature charge out F	570	556	565
Million Btu released per hr	18.6	28.9	27.2
Million Btu absorbed per hr—convection section	1.7	4.1	3.5
Million Btu absorbed per hr—radiant section	12.2	17.0	16.4
Total Btu absorbed per hr	13.9	21.1	19.9
Per cent efficiency higher heating value basis	74.6	73.1	73.2
Per cent stack loss higher heating value basis	23.3	25.9	25.6
Per cent radiation loss higher heating value basis (actually determined)	2.1	1.0	1.2
Btu absorbed per sq ft of convection surface	683	1,649	1,407
Btu absorbed per sq ft of radiant surface	7,720	10,766	10,386
Btu absorbed per sq ft of total surface	3,420	5,189	4,894
Btu absorbed per sq ft of tube surface	6,881	10,446	9,851
Btu released per cu ft furnace volume	7,370	11,450	10,777
Per cent heat absorbed convection section	12.2	19.5	17.6
Per cent heat absorbed radiant section	87.8	80.5	82.4
Temperatures F			
Furnace—(9′ below convection section)	1,195	1,325	1,602
Entering convection section (2 ft below convection section)	1,049	1,312	1,355
Leaving convection section	699	759	793
Hood	632	684	616
Ambient air	65	62	60
Drafts H_2O			
Hood	—.24	—.23	—.23
Stack	—.19	—.16	—.17
Furnace	—.48	—.50	—.55
Flue gas analyses			
Per cent CO_2 entering convection section	10.8	10.5	11.5
Per cent O_2 entering convection section	3.8	4.3	2.6
Per cent CO_2 leaving convection section	10.8	9.9	10.8
Per cent O_2 leaving convection section	3.8	5.2	3.5
Kind of fuel	Refinery gas	Refinery gas	Refinery gas
Btu per cubic ft fuel gas	1,594	1,563	1,575

** Sinclair Refining Company — Houston, Texas.

of the conventional horizontal drum. The steam and water mixture from the fired boiler tubes enter the vertical drum horizontally where it is given a rotary motion by baffling for the separation of water from the steam. The steam liberating surface is therefore a hollow cylinder of water in the vertical plane around the circumference of the drum and the boiler drum is a vertical centrifugal separator that offers many possibilities.

There are four of these boilers in operation. The boilers are designed for 400 psig working pressure and 30,000 to 50,000 lb of steam per hour each. The boiler is bottom supported by the boiler tubes. The circulating return or downcomer is located in the furnace and is insulated to prevent it from becoming a riser. Boiler water circulation should be more uniform than in the conventional boiler as each boiler tube passes through the furnace proper and then through the fin type convection section. The bottom end of the steam drum is surrounded by flue gases and does not require insulation. The boiler is a single pass boiler, has low draft drop and in fact the furnace is a part of the stack.

This type of boiler is not readily adapted for a superheater and where superheat is required a separately fired superheater is used. The Iso-Flow boiler could readily be installed as an economizer as illustrated in Fig. 15. The fuel for the immediate future will probably be oil and/or gas but this type of boiler could be readily adapted to solid fuel firing. The Iso-Flow boiler may have rather extensive applications where fuel oil and gas are the prevailing fuels and where outdoor installations are desired.

Helical Coil Furnaces

The helical coil furnace has many applications from a domestic hot water heater to heating up oil stocks where the heat absorption may be as high as 20 million Btu per hour. Furnaces of this type are used where there is little or no likelihood of coking up or of being plugged. One application for the helical coil is heating up asphalt for tank car loading when it is necessary to load hot asphalt into insulated cars so that asphalt may be taken directly from the cars at point of delivery without heating. Hot asphalt may be transported as much as 1000 miles without cooling off to the extent that it will have to be heated for unloading at point of destination. Another application of the helical coil is the heating up of a mixture of propane and asphalt at a propane deasphalting plant. Small steam superheating helical coil furnaces are frequently used.

The helical coil furnace is normally used only where part time operations are required, where fuel is cheap, and low first cost is desired. It is needless to say that the helical coil furnace is cheap to build. For refinery use the coils are held apart by welded spacer bars about 2 in. long uniformly spaced for supporting the tubes one upon the other. Fig. 21 illustrates the design and application of a helical coil in a furnace.

The helical coil has the disadvantages of inefficiency and probability of plugging up. On the other hand it has the advantages of cheapness and ease and speed of removal and replacement of heating surface. The draft hood is easily removed and then the entire coil can be replaced as a unit.

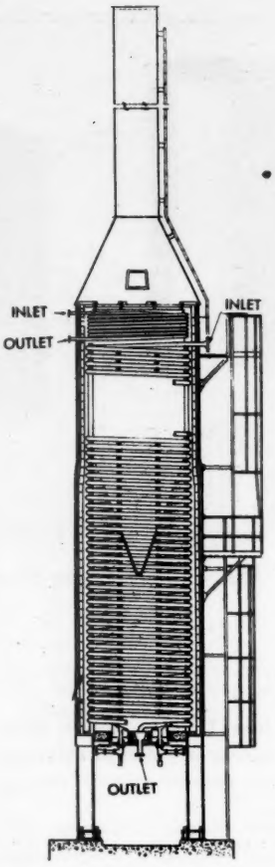

FIG. 21. Iso-Flow furnace. Radiant-convection type, two-flow helical coil.

Miscellaneous Cylindrical Furnaces

Several cylindrical furnaces have been successfully used to burn obnoxious gases and to evaporate foul waters. Horizontally fired gas burners are installed at the base of the cylinder and the foul water is sprayed into the top of the furnace. The same arrangement is used to completely burn up obnoxious gases. In one instance a vertical storage tank was converted into a flambeau by lining the tank with refractory and placing the burners around the base of the tank.

Summary

The cylindrical furnace has a definite place in the oil industry. There appears to be no furnace in an oil refinery where a cylindrical furnace cannot be readily adapted. Its fundamental concept provides for more uniform heat distribution and absorption. In an all radiant cylindrical furnace the coldest tube absorbs more heat than the hottest tube and the furnace adjusts itself with each tube absorbing its aliquot portion of heat in proportion to the fourth power of the absolute temperature difference between the flame and the tube. It can be designed for substantially any duty and efficiency. Each type of cylindrical furnace described in this paper has its place. It is the writer's opinion that the cylindrical furnace is the best when designed with proper understanding and this paper is dedicated to this proper understanding.

Acknowledgments

The writer acknowledges assistance from the Petro-Chem Development Company who furnished Iso-Flow furnace designs, Richfield Oil Company for furnishing photographs of de Florez furnaces, Coen Burner Company for furnishing the original directional flame control burner design, and W. H. Decker, Sinclair Refining Company.

* * *

Midget Plant

A new tiny but tough chemical plant can operate both at high pressure—10,000 psi—up to 1200 F, close to white heat, a combination that hasn't been possible before. The plant was designed and built by C. M. Sliepcevich and G. G. Brown of the University of Michigan, who are using it for small-scale studies of catalytic chemical reactions such as those used in making synthetic rubber or refining crude oil into high-octane gasoline.

The reacting materials entering the plant are heated by special molten salts as they pass through 30-ft coils of stainless-steel tubing. The reaction chamber itself is only 3 ft long and has stainless-steel walls 1¾ in. thick.

BOILING TEST

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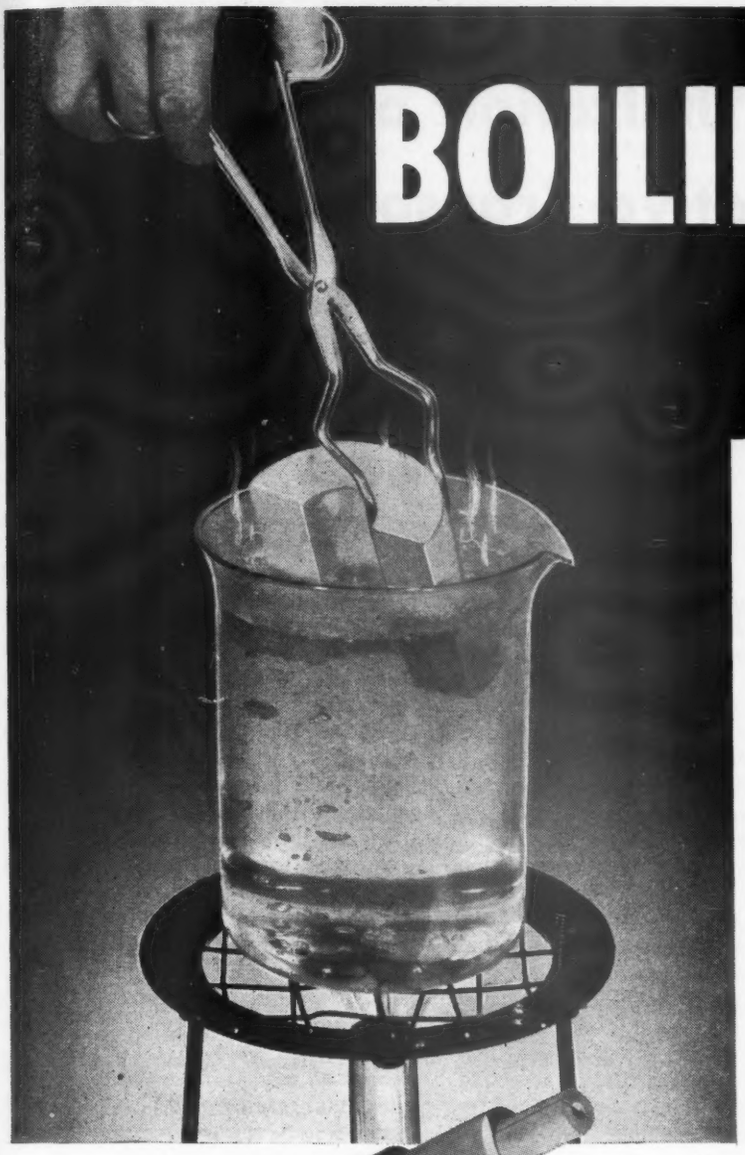

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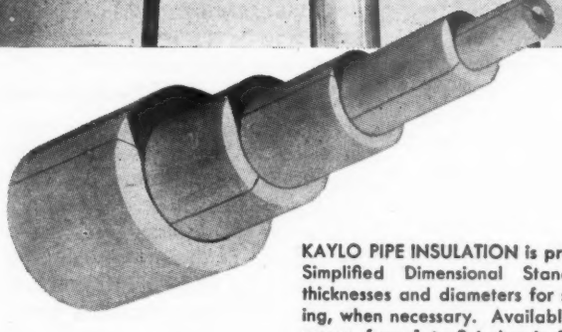
This remarkable new product is available in two forms: Kaylo Heat Insulating Block and Kaylo Pipe Covering. Both are exceptionally strong, lightweight and resistant to moisture damage . . . easy to handle and apply . . . neat and clean in appearance on finished jobs.

The many advantages offered by Kaylo Heat Insulation are appreciated by users in many different industries.



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Trends in the Utilization of Motor Fuels in Automotive Transportation*

Higher Compression Ratios Governed by Economic Balance Between Fuel Cost and Engine-Fuel Efficiency Gained.

J. M. CAMPBELL†

JUST to get a little historical perspective, we will recall that 50 years ago the petroleum industry was a pretty well established business engaged principally in the manufacture of illuminating oils, lubricating oils, greases, and waxes. At that time there was no automotive industry at all and gasoline was considered a waste product.

Today the automobile industry has grown to a point where it consumes 40 per cent of the output of the entire petroleum industry in the form of motor gasoline. The production of gasoline has become a big business.

Today transportation ranks next to food, clothing and shelter in the requirements for living. Transportation is not only a convenience, it is a necessity and the automotive transportation industry alone provides employment for about one out of every seven persons gainfully employed in this country.

Because the petroleum industry must supply the energy for our transportation systems whether they are automobile, railroad, airplane, or ship, it is tremendously important that we continually take stock of our position in regard to the utilization of our energy resources.

Progress in Fuel Utilizaion

During the past 20 years research octane numbers on regular grade gasolines have come up about 20 octane numbers. This is about one octane number per year. At the same time, premium gasolines have increased about 15 octane numbers. Compression ratios have increased from 5:1 in 1930 to 7:1 in 1950.

Our records obtained at General Motors proving ground show that during this same period the average fuel consumption of all domestic passenger cars has increased from 28 ton miles per gallon in 1930 to 39.5 ton miles per gallon in 1949. These figures, representing the average computed at 20, 40, and 60 miles per hour, constitute an overall gain of 41 per cent in efficiency of fuel utilization. It is interesting to note that between 1948 and 1949 there was an increase of 5 per cent in ton-miles per gallon. Although this increase in itself is not impressive, if continued over a period of years it would result in a very significant increase in fuel economy.

Assuming that only one-half the increase in ton-miles of transportation per gallon of fuel has been due to increases in compression ratio and octane number alone, and we think that this is a reasonable assumption, it is estimated that at 1930 rates of fuel consumption it would take about a million barrels per day more gasoline, or over two million extra barrels of crude per day, than we are using today to do the transportation job we are doing with today's passenger car engines. That is a record of conservation that has been made entirely through technological progress—better fuels followed by better engines to use them. And note that I put the better engines after the better fuels because the engine must follow the fuels.

Progress in Gasoline Values

Thirty years ago the tank wagon price of gasoline was 31 cents per gallon in metropolitan New York. The octane number is estimated to have been about 55. Since that time the price of gasoline has been coming down and the octane number has been going up as shown in Table 1:

TABLE 1

Year	c/gal	Approx. Research Octane No.
1920	31	55
1930	14	65
1940	9.2	79
1950	13.7	85

Although the price of gasoline in 1950 is up 50 per cent over 1940, if we consider that the price index on all commodities is up over 100 per cent since 1940, it is clear that today we are getting greater relative value per dollar and better gasoline than at any time since 1920.

This is technological progress that your great industry is passing along to the consumer. It has been accomplished through large capital expenditures and lower unit costs. It is a record that your industry can well be proud of. If we take into account both the lower cost of gasoline to the consumer and the improvement in engine efficiency that has been accomplished through the better utilization of the improved fuels, it can be estimated that we are giving the American public about ten billion dollars of better value annually in the motor gasoline it buys today than it could have gotten at 1920 rates. Of course, if the old costs and rates of fuel consumption still applied we would not have the money to make up the difference and the actual result would be a very great reduction in the use of gasoline and automotive transportation.

Octane Number Requirements

Your manufacturing committee has requested some discussion of the octane number requirements of various automotive engines.

The most complete information on this subject has been published by the Coordinating Research Council under the title "Octane Number Requirement Survey 1948." More complete information including 1949 cars will be published in the 1949 CRC Survey when this report is completed.

The CRC data are based on tests made on cars as found in owner service. For example, Fig. 1 shows the octane number requirements of four different makes of cars as presented in the CRC report.

It will be noted that the octane number requirement of each make of car is not presented as a single number, but as a statistical distribution curve. For example, the curves in Fig. 1 indicate that 50 per cent of the cars of make C required a reference fuel of 82 octane number for freedom from knock. Likewise, to satisfy the require-

*Presented at the 38th annual meeting of The Western Petroleum Refiners Association. San Antonio, Texas, March 27-29, 1950.

†Research Laboratories Division, General Motors Corporation, Detroit, Michigan.

ments of 80 per cent of the cars of make C required a reference fuel of 86 octane number.

This spread in the octane number requirements of each car make is what makes it technically impossible to describe the octane number requirements of cars as found in service except as a statistical distribution curve.

The causes for this spread in the requirements of a given make of car are such variables as slight differences in spark advance, mixture ratio, and combustion chamber deposit. Of these variables, spark advance is probably the most critical.

Most cars today are designed in such a way that the spark advance at low speeds is retarded somewhat from the setting for best power. This is done to prevent excessive detonation and at the same time giving the car owner the benefit of a higher compression engine over the entire operating range than would be possible if the spark at full throttle had been advanced for maximum power. The result is an overall operating economy to the car owner, and it is this principle that has been partly responsible for the gains in fuel economy that have been made over the past 20 years.

At the same time, the application of this principle of spark control makes the octane number requirement of cars extremely sensitive to spark timing. For example, Fig. 2 presents a chart showing the relationship between octane number requirement and spark advance for a certain passenger car engine that is now in production. This figure represents data obtained after normal accumulation of combustion chamber deposit and using primary reference fuels heptane and iso-octane as points of reference on the octane number scale.

The factory distribution limits of ± 2 deg are represented by the cross-hatched area.

It will be observed that at 1000 rpm the factory spark timing corresponds to a loss of about 10 per cent in maximum power. The octane requirement falls between 85 and 88 at this speed, which is about as low a speed as we are concerned with in cars equipped with automatic transmissions.

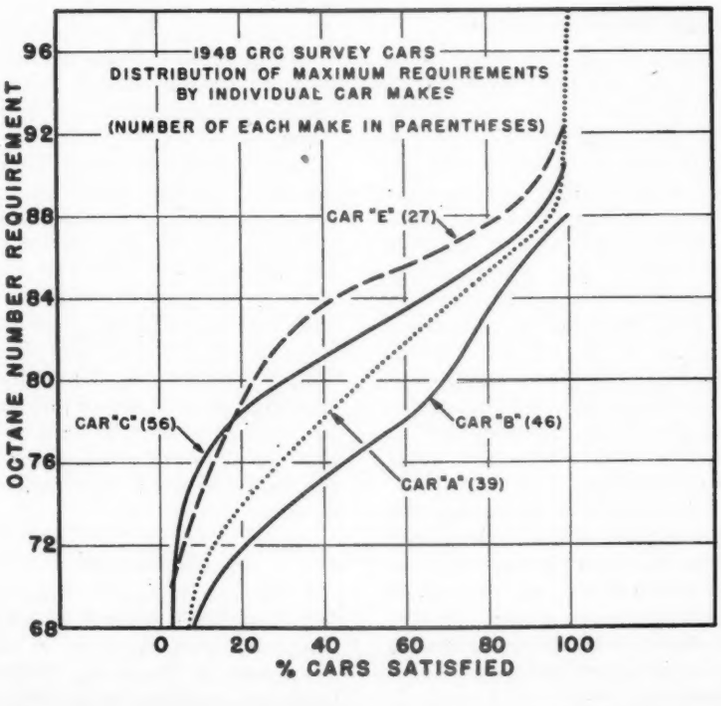
These data indicate that this engine can readily be adjusted to fit a wide range of octane numbers by a relatively small adjustment of ignition timing. The data also indicate that the engine will respond favorably, that is it will produce more power, with fuels up to about 98 octane number.

This diagram illustrates the engineering compromise that must be made in fitting an engine to existing commercial gasolines. This engine was designed to give a commercially acceptable automobile an 86 research octane gasoline. At the same time the engine is capable of realizing better power and improved efficiency by operation on higher octane number fuels provided the ignition timing is suitably adjusted. Also, the engine can be operated on fuels of lower than 86 octane number either by accepting a certain amount of detonation or by retarding the ignition timing beyond the recommended factory setting. In either case, the performance of the car will be impaired to some degree.

Combustion chamber deposits generally add from 5 to 10 octane numbers to the octane requirement of a clean engine, the amount depending on operating conditions and other factors.

Thus it becomes apparent that although this engine might be defined as requiring 86 octane number fuel, in actual service the requirements of this make of engine will be found to cover a wide range of octane numbers according to the ignition setting and other factors that govern in individual cases.

FIG. 1.



Mechanical Octane Numbers

Your program committee has indicated to me that some of the membership of your organization are concened about the possibility that certain improvements in engine design might overnight invalidate their investment in equipment to produce high octane gasoline. I want to reassure you that there is nothing imminent in the automobile industry that we know of that might bring this about. It is a fundamental principle of engine design that high compression gives greater combustion efficiency. This is as fundamental as the law of gravity. To be sure there are other means of getting improved economy, i.e., lower axle ratios, smaller engines, transmission design. But high compression and high octane fuel can always be added on to any improvements that can be made in these other directions. So as we see it today, the engineer will continue to have strong incentives for increasing compression ratios in step with improvements in octane number.

No doubt you have heard of rather phenomenal increases in compression ratio that can be obtained by ingenious engine design but without raising octane number. The automobile industry is very much interested in developments along these lines, and is actively engaged in research in this direction as it has been for the last 40 years. In this connection I would like to point out that some of the engines that are in production today—engines that some of the people in this audience are driving today on regular and premium gasoline—will require 95 to 100 octane number fuel if you try to get every last horsepower that the en-

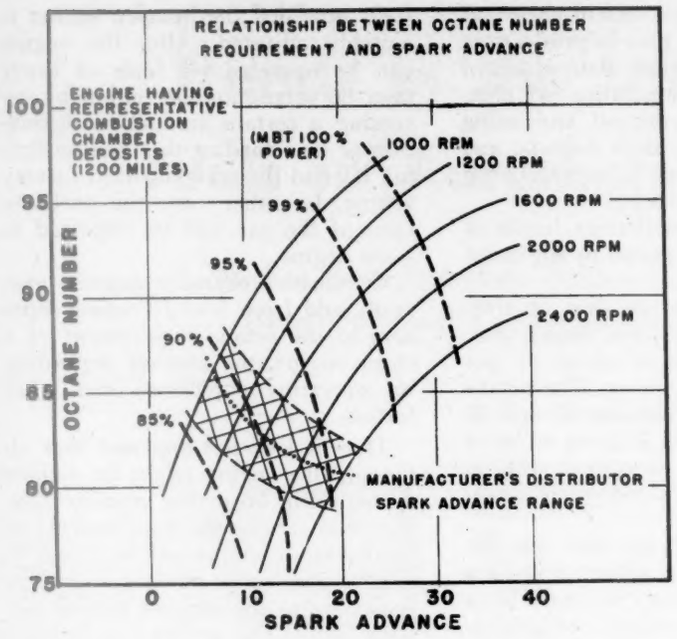


FIG. 2.

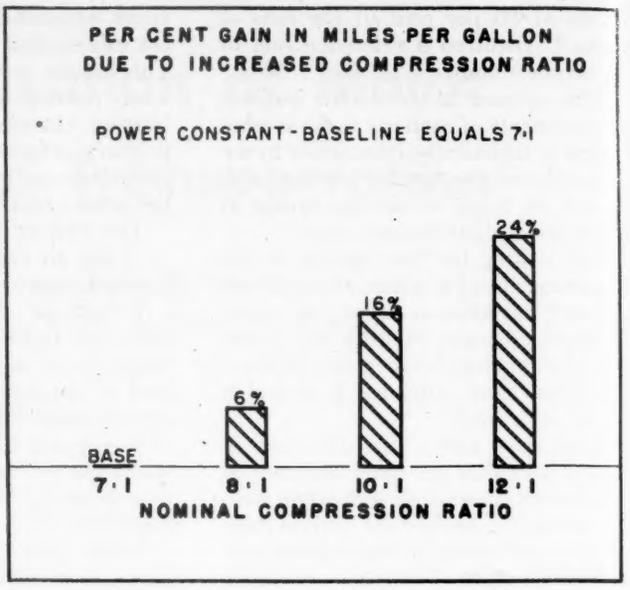


FIG. 3.

gine is capable of producing. In some of these engines, as has already been pointed out, we are sacrificing from 5 to 10 per cent of maximum power by retarding the spark at full throttle to avoid detonation on commercial fuels. But we retain the advantage of the high compression ratio at part load where most of the driving is done.

Engineers are continually at work on combustion chamber shapes, various valving arrangements, and fuel injection. In appraising the possibilities along these lines, however, it must be recognized that octane number requirements are not the only criteria of engine design. Other factors such as durability, cost of construction, and freedom from smoke and objectionable odors are equally important considerations. We have to satisfy our customers with an acceptable automobile engine—and that reminds me of a story—

Some time ago just after the story on atomic energy broke on the country a newspaper man approached Kettering of our organization for a story on how the new form of atomic power was going to affect the automobile business in the post-war period. Ket said he didn't know but he didn't think it would make much difference. Maybe he should go and see a mutual friend who might have more of a story to tell him on this. So the newspaper man called on their friend who said, "Sure. All you will need is a little cartridge about the size of a .22 caliber shell that you will shove down into place and run your car for the life of the car." Some time later the newspaper man ran across Kettering again and he said, "Say, I saw our friend like you said and he told me all about the atomic engine. Surely you knew just as much about it as he did, but why wouldn't you give me a story?" "Well," said Kettering, "you see that is all right, but you know you would have to have about 25 tons of concrete around that thing to protect the driver and I don't think our customers would like that kind of a car. The difference is that we have to satisfy our customers in order to sell cars."

What About the Future?

In thinking about what progress we can make in the future we must always remember that we have to satisfy our customers—the buying public. The public has learned to accept certain standards of automobile performance and economy. Whatever we offer must equal or better our past performance.

If we assume that standards of automobile performance, i.e., power-weight ratio, acceleration, top speed, will stabilize at about present levels, we might expect fuel economy to improve provided technological progress permits higher octane number fuels at a cost that will not more than offset the gain in economy.

Fig. 3 is a chart representing the approximate gain in tank mileage per gallon that has been obtained in tests made by General Motors. In preparing this chart a base corresponding to present average compression ratios of 7.0:1 was taken for purposes of comparison.

In presenting this chart it is recognized that the compression ratios given are nominal values that characterize the respective engines. The effective compression ratios under which fuel is actually burned in these engines will differ materially from these nominal values and will be governed by such factors as valve timing and ignition timing.

Nevertheless, these data that are based on actual tests made in cars indicate the order in magnitude of the improvement in fuel economy that can be accomplished by known methods in engines conforming to present standards of public acceptance.

We all know that the production of fuels to operate higher compression engines costs more money and so the degree to which we can move in the direction of higher compression ratios depends entirely upon finding the economic balance between increased fuel cost and the gain in fuel utilization efficiency.

Over the past 20 years we have made an approximately 40 per cent gain in efficiency of fuel utilization with a reduction in actual fuel cost. Although the way ahead looks difficult to everyone of us, it is hard to believe that we have yet reached the end of the road with such tangible incentives in sight.

Discussion

Chairman McCurry: Gentlemen, Mr. Campbell's paper is now open for discussion from the floor. If you have any question, I'm sure he'll be happy to answer anything up to 1951.

Question: Was this octane requirement that you've shown of some of these gases for optimum operating conditions or just what? For instance, if you were at optimum operating conditions wouldn't we get octane speeds of say 10 to 25 miles an hour when we stepped down on the accelerator?

Campbell: Do you mean that diagram that was on there in the next to the last part? Yes, that's the one. Well, those octane requirements were what it requires to run that car at wide open throttle at that particular speed whatever it was, that is the worst condition for knocking, generally.

Question: Then we would have knocking at lower speeds.

Campell: Whatever the line indicated there.

Question: For instance, at one thousand rpm we would have a great deal of knocking.

Campbell: That is shown by the coordinate on there.

Question: Then that would mean those people with the high octane gas .....?

Campbell: What is that?

Question: Well, if the car is going to knock, it would knock under those conditions, wouldn't it? That is, at those speeds at which they are knocking, therefore they want more high octane gasoline and the refiners have to put out that higher octane gasoline to prevent that knocking, wouldn't they?

Campbell: Well, the diagram indicated just what the octane requirement of that car would be at least the spark advance and speed and it depends upon how that spark sets as to whether that engine is going to knock or not on a given fuel. That's what that diagram represents. I am afraid —I am not sure that you got the meaning of that. ..... right hand line is properly adjusted on this thing and the end points at a distributor range at a thousand rpm you would have probably at least 5 deg of spark advance, and that would require about 86 octane. That means if you had an 86 octane number fuel in the tank that would just give the car a faint trace of knock. It wouldn't be anything to complain about but that's the die-out point the fellows pick when they work out these diagrams. So that means that you need about 86 octane number for that engine.

Question: Would it knock at that point?

Campbell: It would just be a trace knock.

Question: Well, then, the point where you wouldn't have any knock would be up at that hundred, wouldn't it?

Campbell: Put an 88 in there and it wouldn't knock either. See, that is the last trace of a knock that the experts who make this kind of diagrams can hear. When we get these things, we get a whole series of points on here and draw a series of curves and that means with an 86 octane number fuel you just hear a trace of a knock. I doubt if anybody here in the room could hear that knock at all. They open the throttle and accelerate and in order to do this thing you have to have pretty sharp ears. That's what we call a knock die-out point on that engine with 86 octane fuel at 100 deg and you have to have that at a thousand rpm. If you had better fuel and no knock you ran 80 octane fuel in there at that spark advance and at 80 octane fuel you had quite a little knock. Possibly because of the objections and in order to run it at 80 octane without a knock you would have to back the sparks advance about one or two degrees. Get that?

Answer: Yes, sir.

Question: What is the Thompson Vitameter?

Campbell: Well, that's a device that's been proposed that you put on cars to take this last bit of knock out. In other words, here is an engine that we'll say takes 86 octane fuel to run without knocking. With the Thompson Vitameter you could probably run that on 80 or 75 octane fuel without knock according to the supplementary injection of alcohol and lead. It would be a matter of economics as to what alcohol costs against what fuel costs and the weighing advantages and disadvantages of that additional paraphernalia on the car to keep it adjusted. We've got some cars with Vitameters and we're experimenting on a car that's got about a 10 to 1 compression ratio of say 93 to 95 octane fuel in there which represents, in other words, up and down the road a ways when you get to 93 and 95 octane fuel which is all you can get in the next five years or so. Beyond that, you can hardly see ..... so you might say, well, suppose five years from now when we get to that level what are we going to do then? Well, we have Vitameter on a 10 to 1 car which will plug that gap between 95 and 100, once you adapt it, whether then the added cost of the alcohol will more than offset gain in economy. We show with it somewhere around 20 per cent increase in the economy of the gas and the alcohol will cost you more than enough to offset that, why that doesn't look so good. I think you have got to

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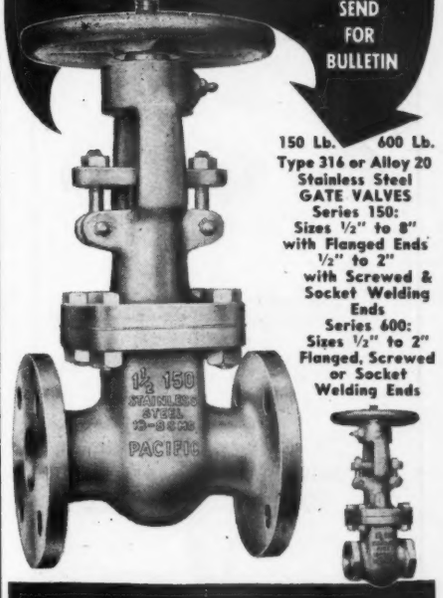

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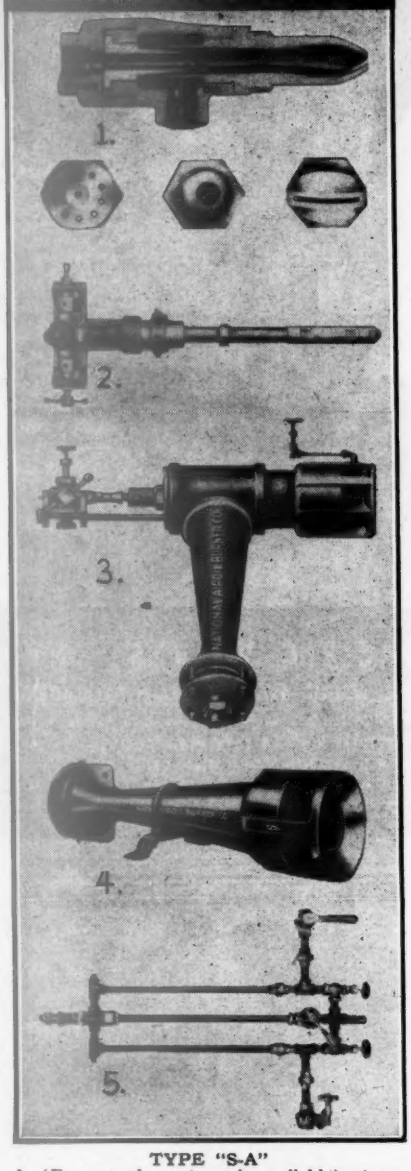

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show the customer a little saving to get him to put the thing on, so it's a matter of economics and customer acceptance and customer acceptance is a very difficult thing to evaluate. Does that answer your question?

Question: I have a question concerning your paper that deals solely with gasoline as a motor fuel. What do you think of the question of diesel fuels and say LPG, versus gasoline in relationship to their production? That is the trend of the three sources of fuel versus gasoline. What is the general outlook in relation to the three in automotive transportation?

Campbell: Well, I think today they are running about 200,000 bbl per day of diesel fuel in railroads, automotive, and marine use, and are making about 10 times that much motor gasoline. It doesn't seem very likely that the diesel fuel is going to catch up with the motor gasoline except is going to increase utilization on the railroads and others. LPG is something that we have considerable interest in at the present time, and I don't know what the answer would be if the price stays attractive long enough to attract the automotive industries. I know some of the manufacturers are in it now and that is how some of these things have to start—in a small way and find out the thing is pretty good and once the operators find they can make a dollar by going to propane they are going to do it. It's just a matter of economics to the operator as to whether he uses propane or gasoline or diesel fuel. Show him how he can make a dollar by using diesel fuel or propane, and he will clamor for it and when the manufacturer sees that he can sell some of that he is going to go right in there after that market. I wish we knew just what the situation will be on this. Maybe some of you fellows here know more about it. I would like to hear a little more about this propane, how long we can count on a low price for it.

Question: What about engines using low octane fuels reported to have been designed instead of engines requiring higher octane number fuels?

Campbell: You mean the engine The Texas Company has been working on. It's a very interesting development, and I think everybody in the business is interested in that type of development. There has been a great deal of work done on that line in the past and I don't see any reason why it should not continue. An engine of that type was developed a number of years ago trying to accomplish that same objective. The Waukesha Company had it in production for a number of years as a universal fuel engine. It has advantages and also a number of disadvantages. It has the same difficulties as any commercial engine. Fuel injection engines are apparently an expensive engine; diesel engines also are expensive engines. The diesel engine has some tough competition to meet with gasoline engines on account of first cost. The diesel fuel economy has to more than offset that fuel cost in order to get the diesel engine in the picture, so that it generally has been restricted to users consuming a lot of fuel. Now if we have an engine of that type built that will be dependable in service and you can make a fuel at a low enough cost you can get into that business. Only time will tell. As I understand it, I think The Texas Company is to present a paper on that engine at the SAE meeting in June. Several manufacturers as I understand it that will make a conversion for most any kind of a truck engine you have.

Question: We operate 16 trucks on propane or butane, whichever we have an excess of, and was just wondering if you have equipment to operate automobiles the same way?

Campbell: Well, as I understand it those companies that manufacture that type of equipment will convert automobiles to this fuel. A number of conversion units have been built. There's some question whether or not you can sell that equipment to the man in the street, but if you have a tank of that in the refinery from which you can fill up, why it's good fuel. The difficulty there in passenger cars is a matter of convenience in handling a liquid fuel, and getting it from coast to coast in this country. Sometimes, we take a lot for granted. But liquid fuel is ideally suited for motor vehicles. We, in this country, have a very uniform grade of fuel, coast to coast and north to south. In the transportation fundamentally we want to go places and fill up with the same kind of stuff there and operate as well as in the place where you came from. We have a big country, and it is important to have geographical distribution so that we can get uniform fuel at all points. Now, the question of propane in a passenger car is up against a distribution problem. If the customer runs out of fuel he will not want to go 5 or 50 miles to hunt up a propane station when maybe he can coast into a gasoline station. One experience like that and he says to heck with that stuff. In commercial operations that's a different story, supply and distribution can be assured. * *

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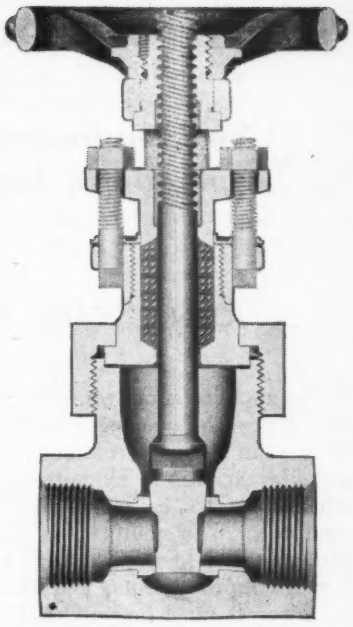

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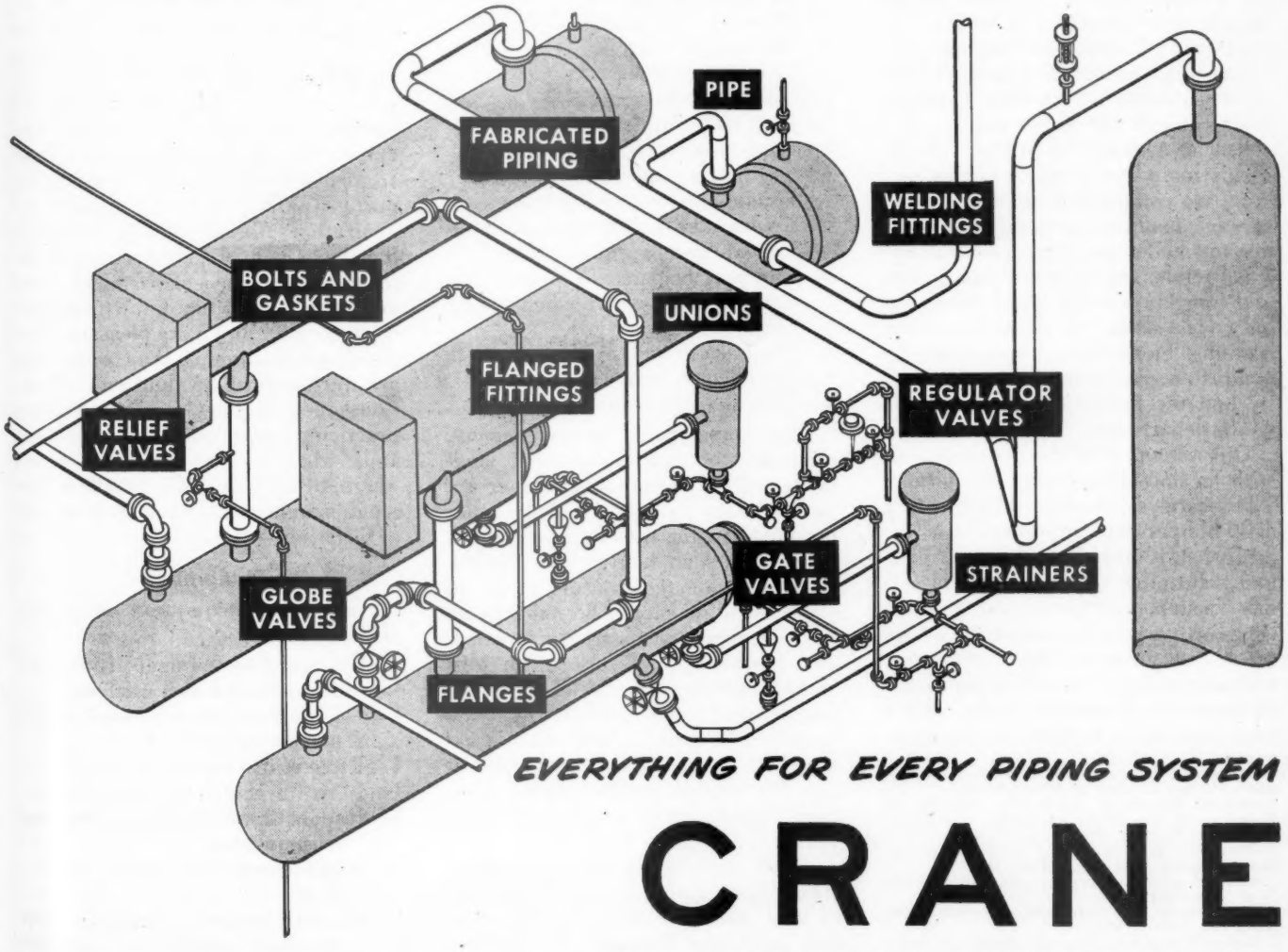

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Maintenance Practices in a Small Refinery*

To keep limited equipment in good condition and protect flexibility of operations, the maintenance department in a small plant must work smoothly and with great versatility.

JOHN S. PFARR[1], ROBERT W. POLLARD[2], LEON T. HARRIS[3], WILLIAM F. DOUGHERTY[4]

In the modern small refinery one will find almost the same processing equipment as in the large refinery, with one notable exception. That exception is what is known as spares or standby equipment. The small refiner must use his capital to keep pace with technological improvements, and these improvements must be purchased at the barest minimum cost which, as a general rule, does not include much duplication of equipment. Such spares as are found absolutely essential are added later after experience has shown where the dollar spent will bring in the greatest return. For this reason maintenance practices in a small refinery are of paramount importance.

Inasmuch as a small refiner's equipment, because of smaller capacity, costs as much (or more) per barrel to construct as that of the large refiner; as his main raw-product (crude oil) costs are comparable per barrel; and as other materials probably cost more due to smaller quantity discounts, the small refiner can keep his costs in line and compete with the large refiner for only one reason, viz., flexibility of operations. Flexibility of operations depends to a great extent on the versatility and the flexibility of the maintenance department.

Our refinery consists of a crude unit with an 8500-bbl-per-day capacity; a TCC† catalytic cracking plant, with a 5000-bbl-per-day reactor-charge capacity; an 1800-bbl-per-day UOP thermal reforming unit; a 1000-bbl-per-day vacuum unit for asphalt production, with auxiliary oxidizing equipment; steam-generating equipment with a capacity of 50,000 lb per hour; 60 storage and rundown tanks, with a total capacity of 472,000 bbl; a tetraethyllead (TEL) plant; control and research laboratories; truck and tank-car loading rack, and the normal auxiliary equipment that would be expected in a plant of this size.

Personnel

Our maintenance department, according to personnel records, is made up of 34 men, listed as follows:

1—Maintenance superintendent.
1—Machinist foreman.
1—Pipefitter and labor foreman.
1—Painting and insulating foreman.
1—Electrical foreman.
1—Instrument engineer.
1—Pipefitter first-class sub-foreman.
1—Storeroom manager.
1—First-class welder.
1—First-class carpenter.
1—First-class painter and insulator.
1—First-class machinist.
1—Second-class machinist.
1—Second-class pump mechanic.
1—Second-class painter and insulator.
3—Second-class pipefitters.
6—Pipefitter helpers.
1—Painting and insulator helper.
1—Carpenter helper.
3—Yardmen first-class.
2—Yardmen second-class.
3—Process extra board.

The maintenance superintendent, electrical foreman, instrument engineer, and the storeroom manager are on the salary payroll. All of the other personnel in the maintenance department are on an hourly rate. Such a system eliminates confusion as to when overtime should be paid, as all of the foremen are working foremen, and frequently are working on jobs alone. The men are shifted by the maintenance superintendent as the various jobs require, and are not assigned to a particular department except for normal routine work (something which rarely exists in a small refinery).

As an example, the first-class welder is kept busy approximately 75 per cent of his time on welding. The painting and insulating foreman is a trained welder, however, and the master mechanic is proficient in that work. Whenever a job arises wherein welding will be the bottleneck, all three are put on this job—either together or on shift work—with helpers being assigned as required. Occasionally, even this flexibility will not meet the requirements, and we may have to get on the telephone and borrow a welder or two from a neighboring refinery. This is always an easy task, as these refinery people know that we shall be ready at any time to lend our craftsmen in an emergency.

However, the records of the maintenance-department personnel by no means tell the entire story. We have on each shift one man on the crude unit, three on the TCC unit, two on the reformer, one at the asphalt plant, one pumper, one at the boiler house, and one at the truck-loading dock. These 10 men per shift are an extremely important part of our maintenance organization. Almost without exception they have had valuable training in the regular maintenance department. Even more important, they know that their work is easier and more pleasant when their unit is running than when they are starting it up or shutting it down. Consequently, they are at all times practicing preventive maintenance; and, whenever an occasion arises wherein they can safely handle minor repair maintenance, they do it as part of their job.

Equipment

The maintenance equipment consists of the following:

1—2½-ton International truck with 20-ton winch and a frame.
1—1½-ton Ford combination flat-rack and dump truck.
1—1-ton Willys stake-rack truck.
1—1-ton International pickup truck.
1—Jeep, equipped for light bulldozing or snow plowing.
1—International caterpillar tractor, T-20.
1—Gibson tractor, equipped with mowing sickle to operate through a 90-deg arc.

*Presented at a session on refinery maintenance during the 15th Mid-Year Meeting of the American Petroleum Institute's Division of Refining, in the Hotel Cleveland, Cleveland, Ohio, May 3, 1950.

[1]Vice president in charge of manufacture, Leonard Refineries, Inc., Alma, Mich.

[2]General superintendent, Leonard Refineries, Inc., Alma, Mich.

[3]Maintenance superintendent, Leonard Refineries, Inc., Alma, Mich.

[4]Refinery engineer, Leonard Refineries, Inc., Alma, Mich.

†TCC = Thermofor catalytic cracking.

3—Chrysler engine-driven Byron-Jackson PUP pumps, mounted on skids.

2—Chrysler engine-driven Hammond 500-gal-per-min fire pumps, mounted on wheels.

2—Foam generators.

1—Trailer foam carrier, 3-ton capacity.

3—2-in. gasoline-driven centrifugal pumps mounted on wheels.

1—International P-12 with 3-in. herringbone gear pump.

1—International P-12 with 4-in. herringbone gear pump.

1—Thor turbine sump pump, air-driven.

1—Safeway portable steel scaffolding equipment to produce scaffold 3 ft x 4 ft x 40 ft; 3 ft x 8 ft x 20 ft; 6 ft x 8 ft x 10 ft; or other proportionate sizes.

1—2-in. portable Beaver threading and cutting machine with attachments to 6-in. (Practically all pipe work over 2-in. is welded).

1—Hydraulic cold pipe bender with dies to 4-in.

1—6-ft bed lathe.

1—8-ft bed lathe.

1—Bench lathe.

1—Drill press with chucks to 2-in.

1—Drill press with chucks to ½-in.

1—50-ton hydraulic arbor press.

1—1-ton hydraulic floor crane.

1—Kalamazoo metal-cutting band saw.

1—300-amp electric-driven welder.

1—300-amp gasoline-driven welder.

3—Acetylene welding outfits.

1—Type "S" metalizing machine (Metco).

In addition to the major equipment just listed, our maintenance department is adequately supplied with all of the necessary small tools which would be expected to be on hand as auxiliary to the foregoing list.

Division of Maintenance

In discussing maintenance practices, we believe that they should be listed in three main divisions:

The first of these we would classify as housekeeping.

We list this phase of maintenance first because we believe that it is first in importance. We have been accused of bordering on the fanatical in the manner in which we stress this subject. We are firmly convinced, however, that the money spent in good housekeeping pays large dividends. Our control rooms are not tile and marble, and we have no gold plate in the refinery; but we believe that we have one of the cleanest refineries in the country. We have a large number of visitors who go through the plant, and a large percentage of these write us complimentary letters concerning the appearance of the plant. These letters immediately become a part of our maintenance program; i.e., copies are made and are put on the bulletin boards of each unit and the locker room. This, we believe, helps to uphold the pride of each employee in this phase of his job.

The operators of each unit are responsible for the appearance of their unit. They do the following work themselves:

1. Wash, with hose and hot water, all floors of the unit, each shift. If the floor is dirty from an oil spill, a hot solution of Oakite Penetrant and kerosine is used in those spots.
2. Keep all packing glands on valves and pumps adjusted so that there are no leaks. In an emergency, they are to add necessary rings of packing. In the case of pumps on which leakage cannot be avoided, and when it is not practical to pipe this leakage to a drain, they maintain pans underneath the gland.
3. Clean up any spills as soon as possible. Major spills, of course, are handled by the maintenance department.
4. Pick up all trash, rags, etc., around the unit and put them into closed receptacles for that purpose. During spring, summer, and fall, each morning before the shift change, the limestone-chip-covered area around the unit is raked.
5. Inspect a job before the maintenance department is released from its responsibility for proper performance of the job, and before the operators again assume responsibility for the appearance of that particular part of the unit.
6. Request assistance, through the assistant superintendent, from the maintenance department when operators are temporarily unable to keep their unit in shape. This is usually due to some operating difficulty.

The maintenance department is responsible for the following duties in the housekeeping phase of maintenance, without special requests from either the general or assistant superintendent:

1. Maintain clean and sanitary conditions in the following:

a. Locker room.
b. Plant offices.

Work in locations (a) and (b) requires the services of one man full-time.

c. Water pump house.
d. Truck-loading pump house.
e. Fire house.
f. Washes all windows in plant except locker room, plant office, laboratories, and boiler house. (Laboratory and boiler-house personnel wash their own windows).

The work from (c) through (f) requires the services of one man full-time.

2. Two men and a pickup truck are scheduled one-half day each day for general plant cleanup. These men empty all trash and rubbish barrels, deliver all used valves and fittings to the salvage department, and assist the units when so ordered.

3. On Saturday morning the personnel of the entire maintenance department, except those on emergency jobs, take over the general plant cleanup. From 8 a.m. until 12 noon they work in cleaning and putting in order all shops, trucks, and equipment. The maintenance department does not work on Saturday afternoon or Sunday.

Painting

Another phase of our housekeeping program is painting. One department is devoted to painting and insulating. We have found that such an arrangement makes an ideal combination, because the general insulation maintenance, such as patching, can be taken care of as part of the preparation for painting. Of course, during regular shutdowns for inspection, the painting is stopped for the length of time required to remove, replace, and repair the insulation of the particular unit involved.

This department—composed of a working, painting, and insulating foreman; one first-class painter and insulator; and one second-class painter and insulator—spends the major part of its time painting.

RADAR SPEEDS OIL SHIPMENTS

Oil shipments by tanker and barge are being speeded by radar. On barge operations particularly, radar helps prevent propeller damage by warning against the approach of heavy driftwood and sand bars. Barges also use ship-to-shore telephones to keep oil storage terminals advised of expected arrival time.

We list the cost of such painting for two typical years, as follows:

1945

405 gal of aluminum paint, at $4.09 per gal	$1,656.45
125 gal of all other colors, at $3.75 per gal	467.50
100 gal of red oxide primer, at $2.55 per gal	255.00
3,320 man-hours of labor, at $1.33	4,415.60
	$6,794.55

1948

589 gal of aluminum paint, at $4.40 per gal	$2,591.60
189 gal of all other colors, at $4.70 per gal	888.30
120 gal of red oxide primer, at $3.37 per gal	404.40
3,846 man-hours of labor, at $1.78	6,845.88
	$10,730.18

It will be noted that the man-hours vs. gallons of paint used were high. The reason for this is that practically all of the painting consisted of pumps, towers, lines, small rundown tanks, and other similar equipment that takes a large amount of labor for preparation and application.

In addition to this painting program, which we call plant-force painting, we keep rigid appearance standards on our storage tanks. This painting, however, is handled by contract, and the contract is let each spring for the number of tanks that require painting (usually about one-fifth of the storage tanks, or 10 per year).

The same contractor has been handling this work for the past 10 years. We supply the paint, and he supplies the labor for preparation and application. The approximate price for this work for 1948 was as follows:

25,000-bbl tank—	$125 per coat
10,000-bbl tank—	$ 80 per coat
5,000-bbl tank—	$ 65 per coat
2,000-bbl tank—	$ 40 per coat

We let a contract two years ago for the painting of TCC unit, but we found that this type of painting could be done much cheaper, and very much more satisfactorily, with plant painters.

Justification of Housekeeping Costs

Why do we spend the amount of money involved for this housekeeping program?

First, we believe that it is tied in very closely with safety. Rigid controls on housekeeping cannot be maintained along with faulty equipment, leaking gaskets, makeshift repairs, and the like. Policing the unit frequently from the standpoint of cleanliness often calls attention to items which would become hazardous if neglected.

Second, we know that it improves operating conditions and, therefore, improves yields. It is axiomatic that, if an operator is conscious of the appearance of his unit, he will not tolerate sloppy temperature control. Likewise, if he will not permit steam leaks, water leaks, or oil leaks, he will not permit a smoking furnace stack; neither will he permit a tank to overflow, or a product stream to continue to run off specification. We are not operating a refinery in Utopia, and we do not mean to infer that such conditions never occur. We do mean that our operating personnel are acutely aware of proper operating conditions and product quality, and we give a large share of the credit to their pride in the appearance of their equipment.

Third, our sales department and distributors use the plant to a large extent in obtaining new customers. We welcome and encourage our distributors to bring in groups frequently, and experience has shown us the product quality is easily "put across" if the prospective customer has been favorably impressed with the appearance of the refinery. Inasmuch as there would be no maintenance practices without customers, we feel that, again, we have an important point for the housekeeping program.

General Maintenance

The second main division of maintenance we would classify as "general."

This division should be discussed in several categories.

1. Safety. Safety meetings are conducted monthly by the maintenance superintendent. These meetings are held in the locker room at 12:30, the normal time for the lunch period to end. As a general rule, they last approximately one hour. A brief review of the last Michigan-Ohio fire and safety meeting, sponsored by the National Petroleum Association, is given. From our maintenance department, the maintenance superintendent and at least one other man have attended that meeting.

The balance of the time is spent in an informal discussion of items which the men bring up in the interest of safety. The practice of safety by the men is shown by the fact that the maintenance department has completed 10 months without a lost-time accident, as well as a period of 8 years without an accident that could be considered other than minor. There have been no fatal accidents in either maintenance or operations since the plant started in 1936.

The men are all extremely conscientious in their safety program, and at all times they wear protective helmets. Safety shoes are not required, but are recommended; and many of our maintenance-department men wear the approved type.

2. Purchasing and Storeroom. This department is of vital importance to the general maintenance of a small refinery. All stock items are maintained by the well-known system of perpetual inventory and, as a general rule, this runs very smoothly. We carry a warehouse stock of parts, valves, fittings, pipe, and similar of approximately $75,000. Experience has determined that such a stock will take care of 90 per cent of our needs. That unpredictable 10 per cent may mean the difference between a breakdown of one unit for a short time, or a longer breakdown that might force down other units due to their semi-dependency. It is in these emergencies that the purchasing agent must be able to locate the necessary material almost immediately, and to arrange with the maintenance superintendent to get it to the plant. In this respect, the small refiner realizes the importance of purchasing from a manufacturer's agent. Such agent will always work with the purchasing department, and usually he knows where the material is located that can be spared until it can be replaced from the manufacturer. The purchasing agent's work in keeping a small refinery onstream never becomes routine or monotonous.

3. Regular Plant Maintenance. We operate on the plan of standing and special work orders. Standing work orders are numbered from 1001 to 1030, listed as follows:

1001—Topping-plant repair and maintenance.
1002—TCC cleanout and inspection.
1003—Treating-plant repair and maintenance.
1004—Ethyl-plant repair and maintenance.
1005—Asphalt-plant repair and maintenance.
1006—Office-building maintenance.
1007—Crude-unit cleanout and inspection.
1008—Auxiliary-buildings maintenance.
1009—Tank-car loading-rack maintenance.
1010—Truck loading-rack maintenance.
1011—Steam-plant repair and maintenance.
1012—Tank-farm maintenance.

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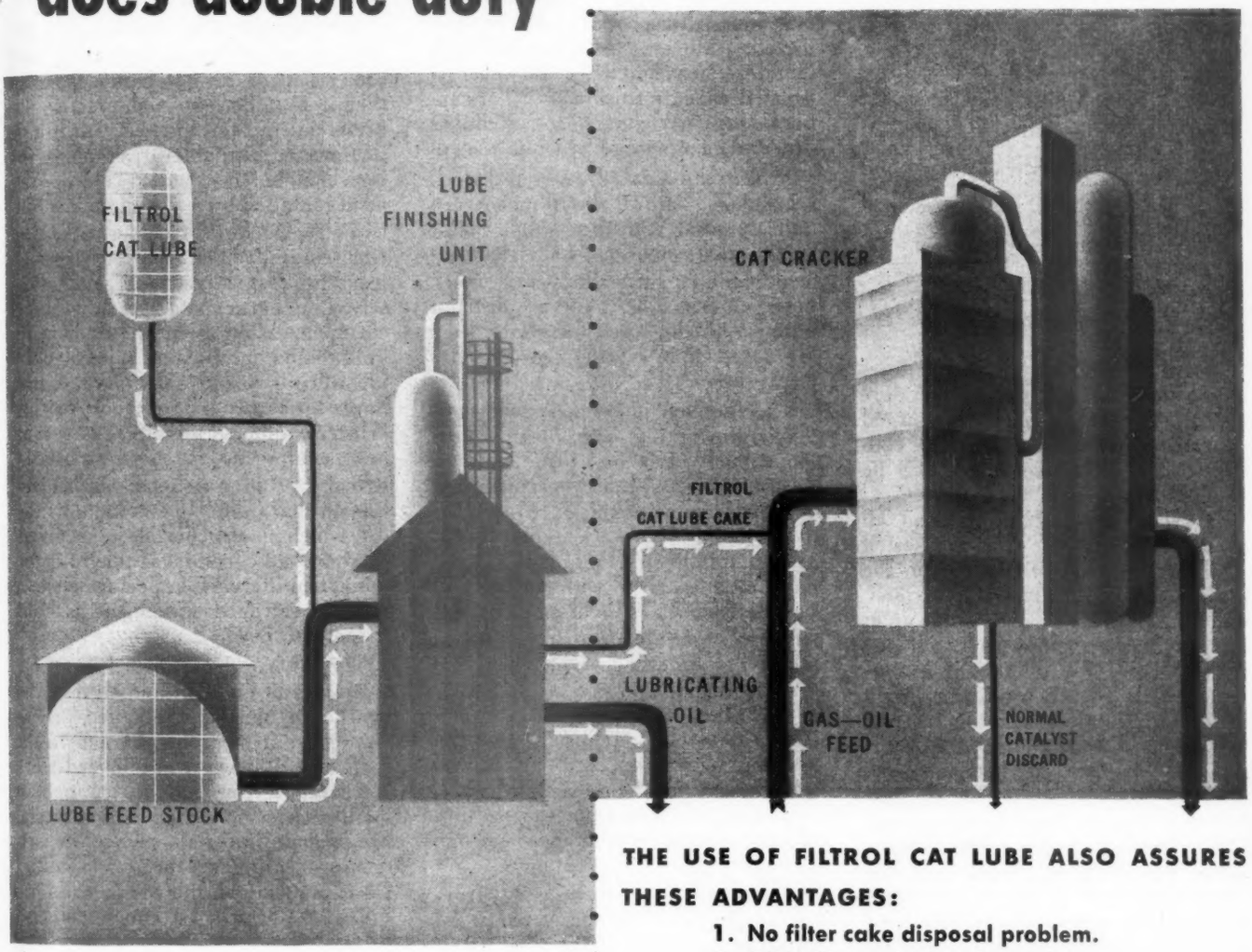

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1013—Control-laboratory maintenance.
1014—Research-laboratory maintenance.
1015—General yard-equipment maintenance.
1016—Oil-separator operating and maintenance.
1017—Water-system repair and maintenance.
1018—Sewer-system repair and maintenance.
1019—Warehouse maintenance.
1020—Closed out.
1021—Closed out.
1022—TCC repair and maintenance.
1023—Parking-lot maintenance.
1024—Sales-department requests.
1025—General plant cleanup.
1026—Reformer repair and maintenance.
1027—Reforming-unit cleanout and inspection.
1028—Closed out.
1029—Lubricating-oil-department expense.
1030—Sales-department service-station expense.

As will be noted, all of the foregoing standing work orders cover only such work that can properly be charged to expense. All work that can be construed as capital investment must be handled by a special work order.

A list of these standing (and all open special) work orders are posted at the storeroom window and in the locker room. All material requisitioned must carry a work order number. Each man, before he goes home, is responsible for filling out a time sheet which gives a brief description of the job, the time spent on the job, and the work order number. If, as is generally the case, the man has been on more than one job during the day, he lists all jobs on the same time sheet. The following morning the maintenance superintendent goes over the time sheets and approves each one. Inasmuch as so few men are involved, and as the superintendent is quite familiar with the location of all work in progress, he can approve these time slips and work order numbers in less than half an hour. Although a time clock is in use and time cards are checked against time slips, the work sheet that is made out and signed by the man himself is the official report used by the payroll department for determining an individual's pay check. Before this plan was adopted, we had had a lot of forgetfulness. Now, however, inasmuch as a man is put to considerable trouble in making out a time sheet after the due date has passed, such neglect is a very rare occurrence.

Special work orders must be requested by the general superintendent. They are numbered serially, beginning with No. 1, continuing through 900 and then beginning again with No. 1. It would be confusing to go beyond 900, as operating-unit charges begin at that point. For instance, during 1948 there were only 37 special work orders issued; thus it can be seen readily that, at this rate, several years would elapse before special work order numbers would be repeated. Consequently, there can be no confusion in allocating labor and material to the proper job. As inferred previously, these special work orders are generally connected with new construction and, therefore, are capitalized. However, if isolated expense work arises that cannot be properly charged to a standing order, then a special order is issued.

Scheduling work. How is the work scheduled? All of the foremen are quite familiar with the routine maintenance that comes under their department and the men who work under them on such jobs. They are also familiar with the work for which they are responsible on the open special work orders.

The foremen place their men, and they are working with them almost immediately after the whistle blows at 8 a.m. The assistant superintendent approves the maintenance requests, as listed in the operators' repair book, at each unit the first thing in the morning and then meets with the general superintendent. As soon as the maintenance superintendent has finished approving the time sheets, he joins this meeting for a general discussion of the status of the maintenance department's work. At this meeting the urgency of the uncompleted special work orders is discussed thoroughly, and often this results in the shifting of one or more men to speed up one or more jobs.

Emergencies. An emergency, from the standpoint of the maintenance department, is a job that must be rushed in order to maintain throughput, or to get a unit back onstream if it has had to be shut down. These are the jobs on which overtime is the rule rather than the exception but, fortunately, they are rare occurrences. Everything, except safety or absolutely essential repair maintenance, is stopped — and everyone concerned is in conference often enough to keep the necessary labor and material on the job until it is completed. The general superintendent, personally, usually handles the coordination of such jobs, because he is in almost constant touch with maintenance, operations, purchasing; and he calls on the administrative management's assistance whenever this is required or deemed desirable.

Emergencies, either night or day, caused by the failure of equipment that needs the attention of one specialist are handled directly by the operator, with the foreman involved and the assistant superintendent being notified as soon as practicable. Examples of such emergencies are the failure of a gas compressor on the TCC unit, the failure of an electrical circuit, or the failure of a vital instrument. These, also, we are happy to state are rare occurrences.

4. *Salvage.* The salvage department is more like an operating unit than a part of the maintenance, except that it is under the maintenance superintendent; and the two men in this section are available at all times for rush maintenance work. This department is staffed by a first-class machinist and a machinist's helper. All material removed on a repair or replacement job is gathered and sent to the salvage department. There it is either cut up and sold as scrap; or it is rebuilt to new specifications, painted for identification, and sold to the warehouse for 50 per cent of the new price. When available, rebuilt rather than new equipment or parts must be issued by the warehouse except for certain hazardous locations or uses for which new material is specified. We have not as yet been able to determine the difference in performance or wear of salvaged equipment as compared with new.

The salvage department has an operations unit number, and all material charged against it is handled just as warehouse material is charged to the TCC unit. Whenever specialized work is required from another branch of maintenance, its labor and material are charged to the salvage department. Occasionally, even specialized labor outside of the refinery is required — which, of course, is also properly charged.

All of these charges, subtracted from the sales to the warehouse and to the scrap dealer, result in a profit or loss to the salvage department. So far it has been a very profitable department, as well as being an important phase of good housekeeping.

One interesting example of the salvage department's work concerns the elevator chain on the TCC unit. As you who are opening TCC units know, a chain has a life of approximately two years. However, it has worn only on one side and, by being rebushed and by having the pins turned, it will have an additional life of approximately two years. We were solicited by a company that had rebuilt several

chains for major oil companies, and it requested the job of rebuilding our chain at a cost of $11.40 per link or, with 634 links, at a total cost of $7,227.60, plus freight on 8 tons to Texas and back. After a discussion of the job with a representative of the manufacturer of the chain, our salvage department stated that it could show a profit at $7.00 per link. This estimate was accepted, and the salvage department was allotted one year to do the job without permission to accumulate normal salvage. In less than 7 months the chain was rebuilt at a cost of $6.18 per link, with purchased material accounting for $3.92 per link. It can easily be seen that this represented a saving of more than $3300.

5. *Construction.* This paper deals with the maintenance practices in a small refinery; but construction, insofar as it is handled by the maintenance department, must be touched upon briefly. Our plant-force construction program is based on the premise that we need trained men to handle abnormal maintenance such as unit shutdowns, cleanouts, and similar. Any construction work that we can do to keep the force busy during the periods of normal maintenance we undertake. Other construction work is contracted for. Naturally, we would not attempt a major construction job; neither would we take on a minor capital improvement if our maintenance department were far behind in its program. Neither the type of the project nor the dollar value is the deciding factor. As an example, our maintenance department constructed a 60 by 120 masonry warehouse building; yet we contracted for a 20 by 40 masonry fire house.

It becomes advantageous at times to undertake a portion of a project and contract a portion. An example of this was the revamping and the doubling of the capacity of our crude unit. The furnace was purchased from Petro-Chem and erected by Fluor; yet the maintenance department erected the prefractionator tower, set in larger pumps from time to time, revamped the lines, and then made the tie-in of old and new equipment during a major shutdown of the unit.

One fairly extensive construction project, which the maintenance department undertook, was the erection of a vacuum tower, two oxidizing tanks, and the construction of a complete asphalt plant. This was a project which required approximately $30,000 worth of labor.

It is very doubtful, unless a change of policy is instituted, whether we can undertake such types of projects in the near future because of the fact that, although the catalytic cracking unit did not materially affect the manpower required for abnormal maintenance, it has added substantial requirements to normal maintenance.

We have, on an average, 12 special work orders open at all times. Most of these come under the category of construction, and they range from 0 to 99 per cent completion. As examples, we list the following work orders open as of January 1, 1949:

215—Convert south bank of tubes in reformer to viscosity - breaking operation.

224—Construct tank foundations and dikes for four 25,000 - bbl tanks.

228—Change over and construct power line to back tank farm; and install Byron - Jackson transfer pump, motor, and necessary piping.

230—Build and install lime-slurry injector for TCC unit.

231—Build and erect new sub-station for west bank of transformers.

234—Install oxygen recorder at steam plant.

235—Install used tank and necessary piping for sulfuric-acid storage at boiler house.

236—Lay concrete paving at truck-loading dock.

237—Install additional caustic - contact tower at treating plant.

238—Install Byron - Jackson pump and Smith meters at truck-loading rack.

239—Build and erect pilot phenol-disposal unit.

240—Construct pump houses for three new water wells.

This type of work order must necessarily be scheduled far in advance because, on an average, only three jobs can be completed in a month, and many are open for six months or longer. It would be disastrous to our maintenance program if we were to call for a triple-A priority on more than one or two jobs at the same time.

Inspection and Cleanout

The third division of maintenance, and the division which determines the minimum manpower, is inspection and cleanout.

At this point may we state that it is our opinion that a tremendous amount of credit for the safe and excellent maintenance practices of a small refiner should be given to the Universal Oil Products Company. Every small refiner who has, or has ever had, a Dubbs cracking unit (and that represents a large number) is aware of the rigid inspection program set up for that unit, and which is maintained on a regular schedule by the inspection department of that organization. One highly qualified metal inspector and, when necessary, additional engineers are sent in to supervise and actually work with the maintenance department during these inspections. Inasmuch as their requirements have always been extremely rigid, yet practical, the result is that both refinery management and the maintenance personnel have become quite conscious of the benefits of thorough inspection and adequate normal and preventive maintenance. This inspection has always been offered as a service, and it costs the refiner nothing over his normal royalty payments. On request, this same service has been extended to crude units and other equipment not under a license agreement. In addition to the inspection, general refinery engineering has been available from this organization for the purpose of assisting a small maintenance department to undertake construction that met rigid specifications. Such type of services has resulted in many of the thoroughly trained UOP personnel accepting responsible permanent positions in these small refineries. In fact, it would be our opinion that there are very few modern small refineries in existence today in this country that do not have one or more UOP-trained men in their personnel; and such men, as a general rule, have substantial weight in establishing maintenance policies. Both our general superintendent and our former assistant superintendent are in this category.

When it appeared that we might select a TCC unit, this inspection and engineering service was given very careful consideration, and we were assured by the Houdry Process Corporation that it was geared for identical services. We are happy to relate that these people have been giving the same thorough inspection and engineering work on the TCC unit as we formerly obtained for the Dubbs unit, and which we are still obtaining from UOP for the thermal reforming unit.

By the experience gained throughout the years, we have been able to set up, within our own personnel, adequate inspection services and records for the balance of our equipment.

Inspection and cleanout shutdowns are exceptionally well-planned and scheduled events. Just as soon as experience shows the frequency rate of a unit, it is set up on a yearly schedule. At the present time we have no units which require inspections more frequently than once per year. We have sufficient minor shutdowns of a few

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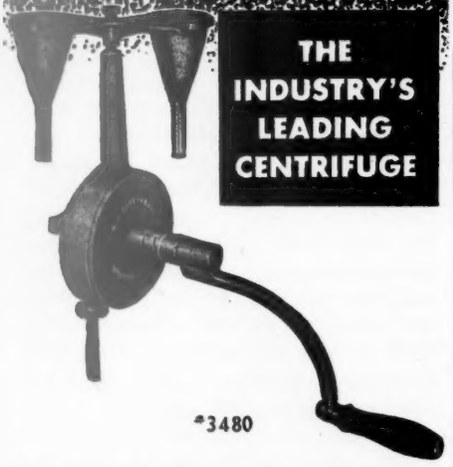

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hours' duration on the units in order that we may spot-check potential hazards in case there has been a significant change in the composition of the charge stock.

The schedule in effect at present is as follows:

Crude unit and one 150-hp boiler—June.

TCC unit, cooling tower, and 350-hp boiler—April.

Reforming plant, LPG unit, and one 150-hp boiler—October.

The TCC unit had been set up for November and April but, after the first two inspections, it was scheduled yearly. The operations budgets are arranged so that product availability does not upset this schedule.

Planning a Shutdown

At least six weeks before the scheduled shutdown a meeting is held, which brings in all foremen and all operating personnel involved who are not on shift at the time. The agenda of such a meeting follows:

1. The shutdown repair book of the unit is discussed item by item, and a decision is reached on each request. (At each unit we have two maintenance books, one for normal and one for shutdown work.)
2. The last written shutdown list is reviewed item by item, and those which need attention for the coming shutdown are checked.
3. The written inspection report from the preceding inspection is discussed point by point.
4. The list of materials which should have been ordered before the meeting is checked in order to ascertain whether the materials have come in and are on hand, or whether they will be delivered on the date indicated.
5. Determine whether a representative of the manufacturer of any major equipment should be requested to be present during all or part of the shutdown.
6. The definite date and time for shutting down the unit is set.
7. The length of the shutdown is discussed and tentatively set.

A secretary is present at this meeting to record each decision made and, when requested, to take a report of any discussion.

As soon as possible after this meeting, a complete shutdown work list, separating the work by departmental headings, is prepared by the general superintendent, and copies are sent to all foremen and posted on the unit bulletin board.

From that point on, the maintenance superintendent is responsible for working closely with the purchasing agent to assure that all material is on the job on time.

One week before the shutdown another general meeting is held, and the maintenance superintendent outlines the work schedule; this schedule gives an estimated man-hour breakdown of the various jobs and the procedure for attack, so that all work will end at approximately the same time. Naturally, such an estimate can only be a guide, and it must be juggled constantly after the shutdown begins.

Lists have been prepared dividing all personnel, except operating, into two 12-hour shifts, 6 days per week. The operating men remain on their regular 8-hour shift, but they act as supervising foremen over a particular section of the unit.

After this meeting the final job and assignment lists are typed and distributed; and, during the week, detailed checks are made of material, special cleanout equipment, and similar.

We admit frankly that we were quite anxious concerning the first turnaround of the TCC unit. We had read of records being made turning around catalytic cracking plants in 21 days with only 360 men. On this basis, it would appear that we could run for six months and clean out for six months. Our maintenance superintendent had spent a lot of his time on the unit during construction, and he consistently insisted that he could take care of the turnaround with his plant force in less than three weeks. The job was completed in 264 hours with an expenditure of a total of 5053 man-hours; 501 hours, or almost 10 per cent, of the turnaround labor was accounted for by the necessitv of replacing carbon-steel lines with 4- to 6-per cent chrome around the tar separator. These lines had been in service for several years on the Dubbs unit, and probably should have been replaced during the tie-in work of the construction project.

The details of this first turnaround were published in the *Petroleum Refiner* 27 [3] March (1948) and, therefore, we shall not repeat the information in this paper.

Outside Assistance

In an inspection of the crude unit, LPG plant, treating plant, and miscellaneous equipment, we require no outside assistance. We have a chemical engineer who normally spends one-half of his time on supervising and working on daily refinery yields, and the other half as combustion engineer. This man is made available during turnarounds, and he works in the ca-

Headquarters Insignia . . .

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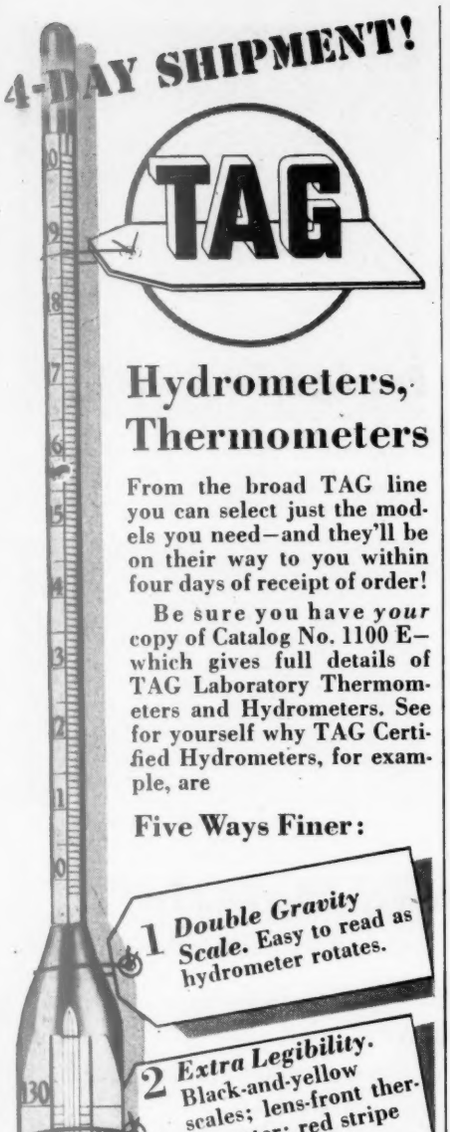
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pacity of metal-inspection engineer. From having worked with Universal Oil Products Company and Houdry Process Corporation metal inspectors, he has become proficient in that capacity. He follows the established procedure of hammer-testing, drilling, and calipering through the open ends of pipes, tubes, and manways. As soon as possible after the turnaround he prepares an extensive report which lists all measurements, work done during shutdown as a result of the inspection, and a schedule of work to be done at the next shutdown. He also keeps a complete record of changes made between planned turnarounds.

In an inspection of a boiler, we request a man from the insurance company; and he advises on the work, approves the boiler, and later submits a complete report on the inspection.

In an inspection of the thermal reformer, we schedule a qualified UOP inspector, and he supervises the job generally and takes all measurements personally with the assistance of our inspector. We are later supplied by UOP with a complete report of the inspection part of the turnaround, which report shows the work completed on recommendation of the inspector and the work to be done during the next shutdown.

In an inspection of the TCC unit, the Houdry Process Corporation sends a qualified metal inspector and two engineers. The inspector supervises the inspection work, and personally takes all measurements with the assistance of our inspector. The two engineers, with the assistance of helpers provided by us, go throughout the entire unit for the purpose of making visual inspections and comparing the results with those of the last written report. Within approximately two months we receive six copies of a very detailed report of the inspection. To give an idea of this report, we list the table of contents of the third inspection report on the turnaround of April 1949 as follows:

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In addition to the Houdry personnel, we request the following outside technical assistance, which is always cheerfully supplied:

An engineer from the Jeffrey Manufacturing Company to inspect and make recommendations concerning the catalyst elevator; approximate time required, 4 days. (On the third inspection, this engineer supervised the removal of the old chain and the installation of a new chain and head shaft. He was on hand for almost two weeks.)

An engineer from the Ingersoll Rand Company to inspect and make recommendations concerning the gas-driven gas compressors (2 days).

An engineer from the Young C. Smith Company to inspect condition of the Murray turbine which drives the main water-supply pump (1 day).

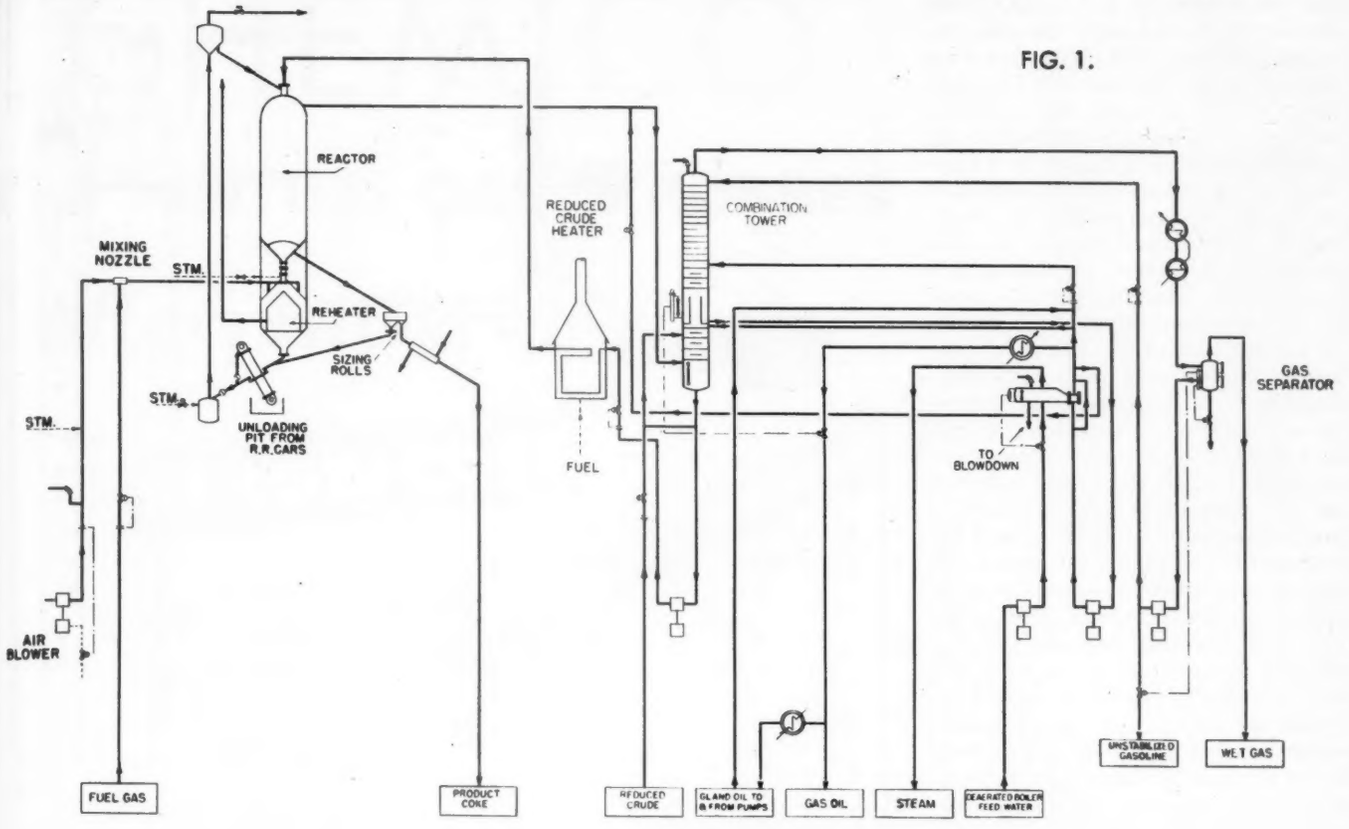
Also, occasional requests for representatives of the company which manufactures equipment which might have been giving trouble or excessive maintenance during the run.

For several years, on any unit shutdown, we worked seven days a week, with no time off until the unit was onstream. For the past two years we have been scheduling our turnarounds on a six-day week, and we find that we get a faster and better job. Even though we pay double time for the seventh day, the men are almost unanimously in favor of the day of rest. Of course, the operators continue on a seven-day week, as their day off is on a regular schedule, but these men are used very profitably on Sunday in general cleanup work around the unit.

We hope that some of you will be able to gain some ideas from our more or less detailed statement of our maintenance practices, inasmuch as a great many of them were brought about by adoption of the ideas of others.

We desire to thank publicly all of the companies mentioned in this paper for their part in assisting us to maintain our refinery in first-class condition. Others, too numerous to mention in a paper of this kind, also are of great help. The main credit, however, must be given to our most capable and most loyal refinery personnel. * * *

FIG. 1.



CONTACT COKING†

New type of process has been developed differing from delayed coking and producing a catalytic cracking unit charge stock.

A. H. SCHUTTE*

THIS paper presents a study of the effect of adding contact coking to the existing equipment in a typical California refinery. This process offers an economical method of converting reduced crudes into maximum yields of cracking stock readily convertible into high quality gasoline. It minimizes fuel oil production in the refinery and releases valuable mid-barrel distillates currently used for fuel oil blending. In order to obtain the maximum benefit from the coking process, additional catalytic cracking capacity should also be provided in order to enable the refiner to meet the present gasoline octane requirements.

†Presented before California Natural Gasoline Association, Los Angeles, October 7, 1949.
*The Lummus Company.

Basically, contact coking consists of applying a residual stock to a continuous stream of preheated coke particles produced in the process. The operating conditions are so adjusted that the charge oil boiling above the range of the desired gas oil product is taken up on the coke particles as a thin non-viscous liquid film. The wetted coke particles are then allowed a residence time of 15 to 40 min in a moving bed maintained at sufficient temperature to convert the liquid oil into gas, gasoline, gas oil, and coke. By properly adjusting the coke to oil ratio and the particle size range of the circulating coke stream, a free flowing condition is obtained and the bed particles may be readily drawn off and reheated for recirculation to the oil contacting zone.

Development work on this coking process has been carried out during the last 6 years and has been described in an earlier publication. The data and experience obtained from this work give a firm basis for the design of large commercial units.

A typical contact coker flow diagram is shown in Fig. 1. If the reduced crude charge contains material boiling in the desired product gas oil range, it may be fed to the bottom section of the synthetic tower and the virgin gas oil directly distilled. The reduced crude and recycle from the bottom of this tower is then preheated in a conventional oil heater to a nor-

mal temperature of 800 to 850 F and thoroughly mixed with the coke circulating stream in a contacting zone located above the reactor. The coke flows down through the reactor, through a sealing zone and enters the reheater where it is heated by a combination of radiation and convection to the proper temperature for recirculation. In the unit shown, the coke recirculation is done by means of a pressure lift. The coke particles grow in size approximately one thousandth of an inch with each pass through the reactor and net coke production manifests itself as an increase in reactor inventory. Product coke is drawn off to maintain the inventory essentially constant. Usually the largest particles of the circulating stream having a major dimension of ¾ of an inch are withdrawn as product through a sizing device; either by screening or by elutriation. The circulating coke in the unit will normally contain particles ranging in size from $\frac{1}{16}$ in. to ¾ in., and in order to prevent a general increase in particle size, an adjustable sizing crusher is provided that may be set to crush the largest particles in a small recirculating stream. As the coke is laid down in very thin layers, and is subjected to partial calcination in the reheater, it is high in density, low in volatile matter, and high in mechanical strength.

The plan and elevation of a typical contact coker is shown in Fig. 2. It will be noted that the arrangement is compact and that no water circulation and clarification equipment is involved. The product coke may be run directly to shipping cars alongside the unit or it may readily be transported as a dry, uniform size material to storage, or to points of use, if it is being burned in the refinery.

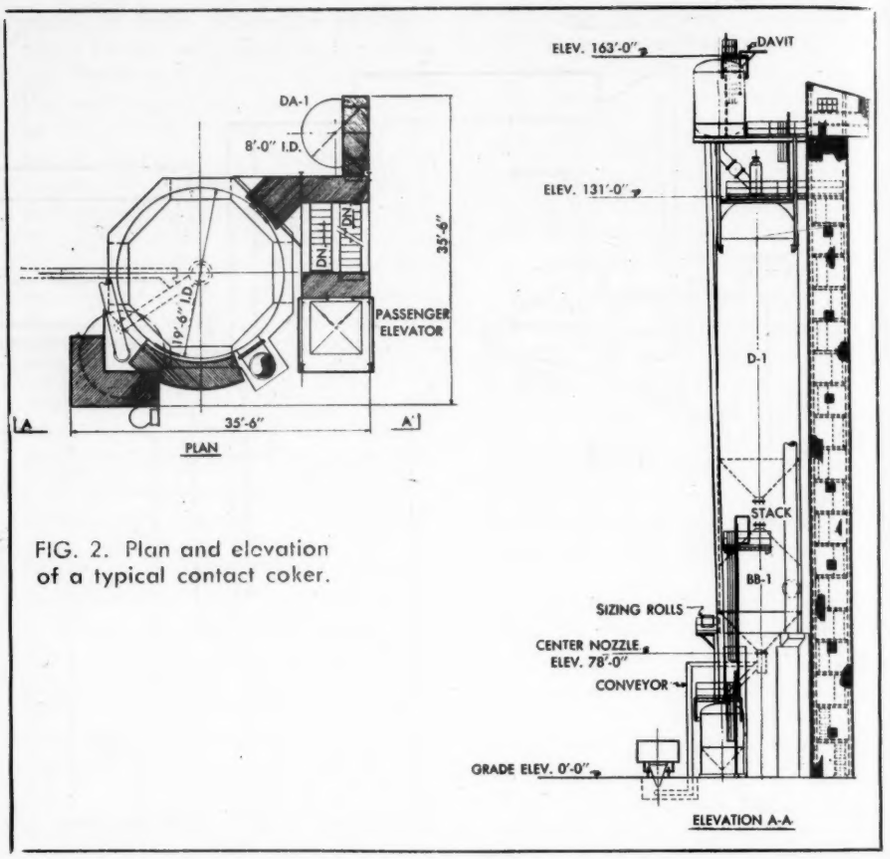
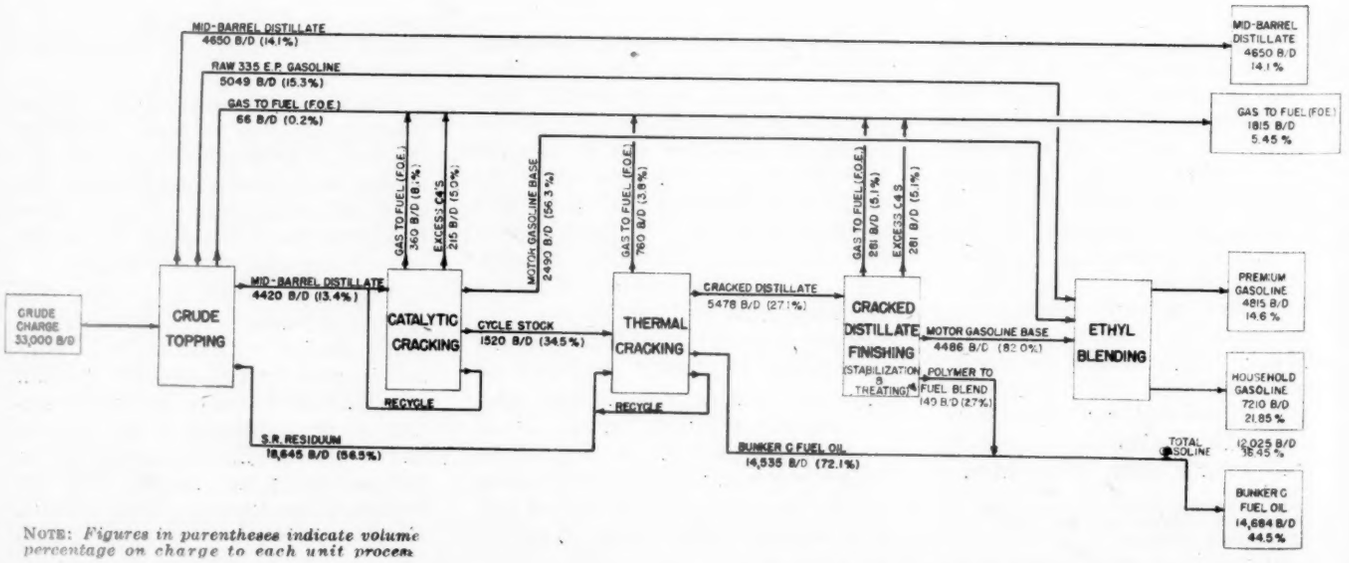


FIG. 2. Plan and elevation of a typical contact coker.

In order to show the effect of adding contact coking and additional catalytic cracking, a typical refinery situation shown in Fig. 3 has been chosen as the original case with the refinery operating without coking facilities. In this case, the refinery is charged with 33,000 bbl per day of 24 gravity Wilmington crude and operates with crude topping catalytic cracking, thermal cracking, and distillate treating. The products are gas, mid-barrel distillates, premium and house brand gasolines, and Bunker C fuel oil. It will be noted that the total gasoline production amounts to 36.5 per cent and Bunker C fuel oil to 44.5 per cent on crude.

Case A shown in Fig. 4 charges the

FIG. 3. Original case—no coking—33,000 bbl a day of 24° API crude.


MID-BARREL DISTILLATE 4650 B/D (14.1%)
RAW 335 E.P. GASOLINE 5049 B/D (15.3%)
GAS TO FUEL (FOE) 66 B/D (0.2%)
GRUDE CHARGE 33,000 B/D
CRUDE TOPPING
MID-BARREL DISTILLATE 4420 B/D (13.4%)
GAS TO FUEL (FOE) 360 B/D (1.8%)
EXCESS C4'S 215 B/D (0.9%)
CATALYTIC CRACKING
MOTOR GASOLINE BASE 2490 B/D (56.3%)
CYCLE STOCK 1520 B/D (34.5%)
RECYCLE
S.R. RESIDUUM 18,645 B/D (56.5%)
GAS TO FUEL (FOE) 760 B/D (3.8%)
THERMAL CRACKING
RECYCLE
CRACKED DISTILLATE 5478 B/D (27.1%)
GAS TO FUEL (FOE) 281 B/D (5.1%)
EXCESS C4'S 281 B/D (5.1%)
CRACKED DISTILLATE FINISHING (STABILIZATION & TREATING)
MOTOR GASOLINE BASE 4486 B/D (82.0%)
POLYMER TO FUEL BLEND 140 B/D (2.7%)
BUNKER C FUEL OIL 14,535 B/D (72.1%)
ETHYL BLENDING
MID-BARREL DISTILLATE 4650 B/D 14.1%
GAS TO FUEL (FOE) 1815 B/D 5.45%
PREMIUM GASOLINE 4815 B/D 14.6%
HOUSEHOLD GASOLINE 7210 B/D 21.85%
TOTAL GASOLINE 12,025 B/D 36.45%
BUNKER C FUEL OIL 14,684 B/D 44.5%

NOTE: *Figures in parentheses indicate volume percentage on charge to each unit process*

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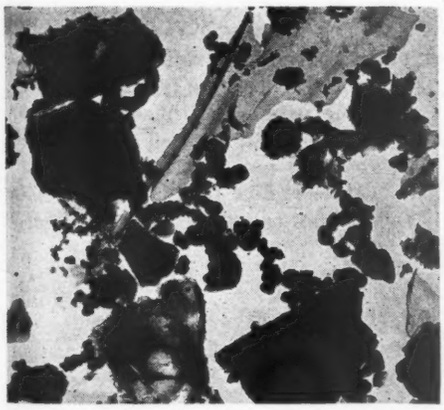

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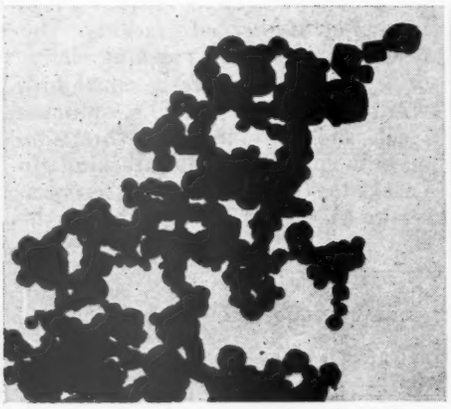
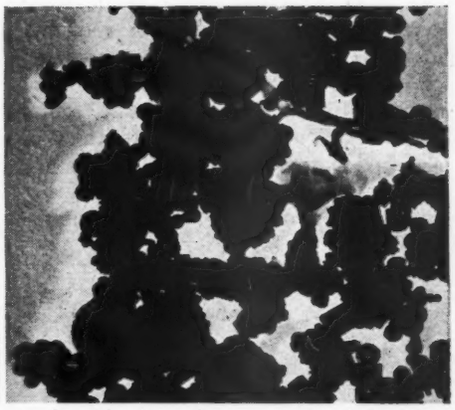


Iron oxide dust from oxygen-lanced open hearth. P-A Venturi Efficiency . **99%**



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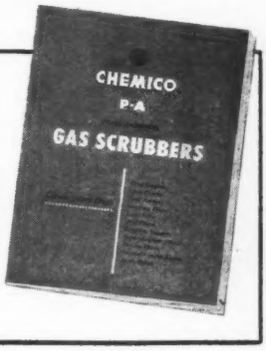

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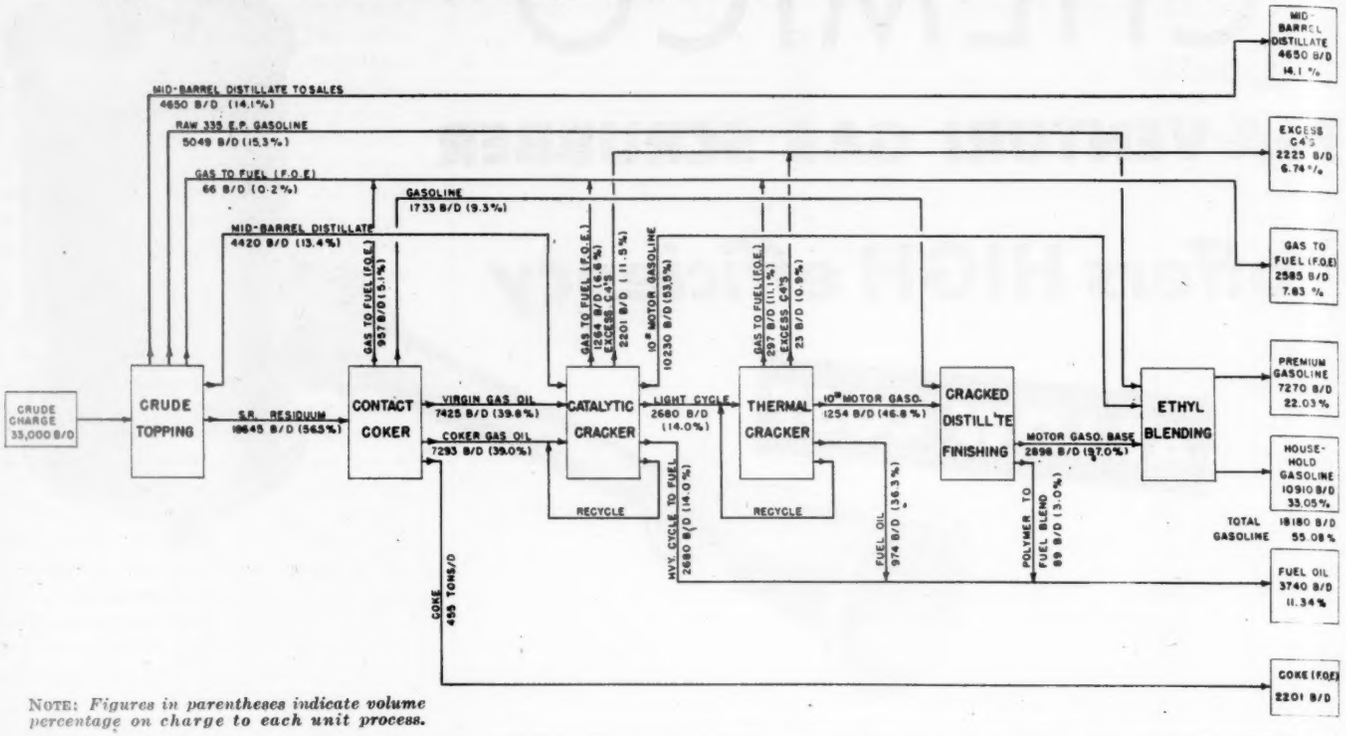
FIG. 4. Case A—Contact coking and recycle catalytic cracking—33,000 bbl a day of 24° API crude.

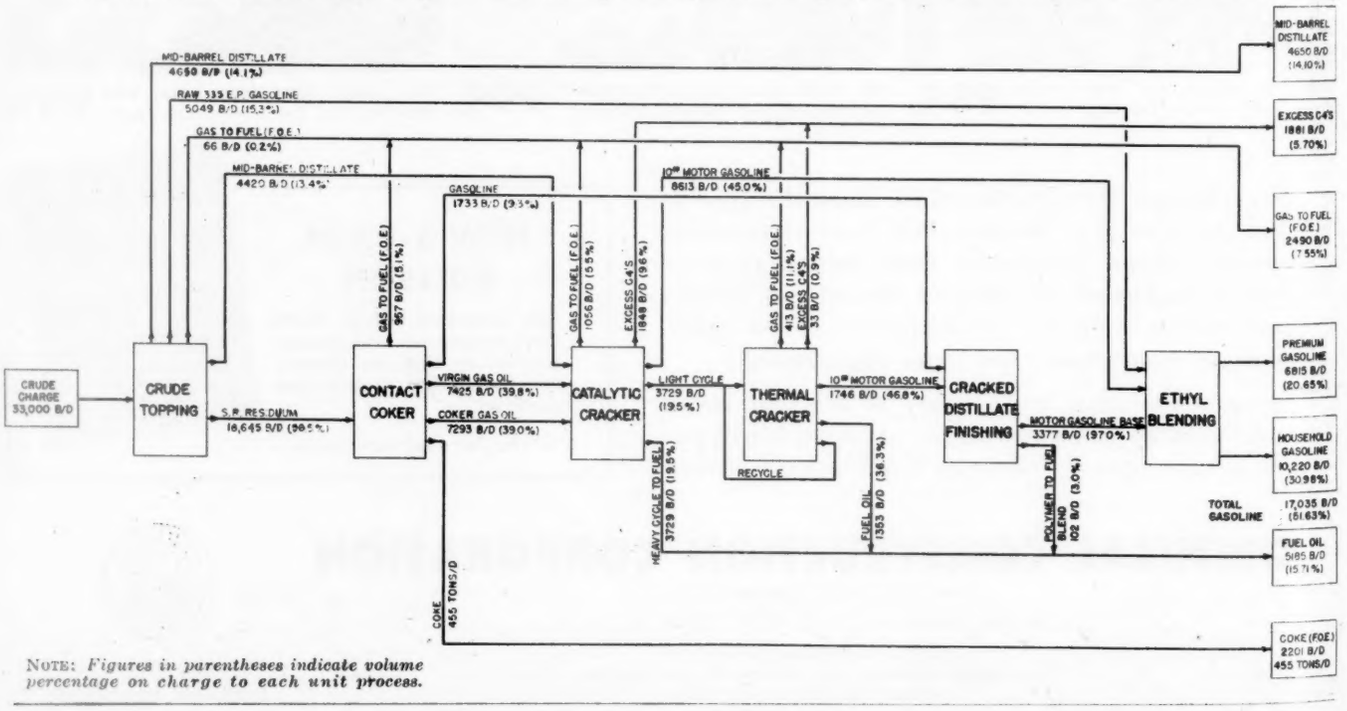


NOTE: *Figures in parentheses indicate volume percentage on charge to each unit process.*

same crude as the original case with the same products from crude topping, but in this case the reduced crude is charged to a contact coker producing catalytic cracking stock as a major product. As the charge to the contact coker is not subjected to the elevated temperatures involved in conventional delayed coking and as the vapors are removed from the contact coker reactor at the top of the bed, the product gas oil is subjected to a minimum of thermal cracking. This results in a catalytic cracking charge of a quality very nearly equal to a virgin stock and permits optimum yields and minimum coke formation on subsequent catalytic cracking. In Case A the catalytic cracking has been set up at 0.7 to 1 recycle ratio, the excess light cycle stock being cracked in an existing thermal cracker and the heavy cycle going to fuel oil. It will be noted that when producing the same mid-barrel distillate yield, the total gasoline production has increased to 55 per cent and the fuel oil decreased to about 11 per cent on crude.

A lower investment cost for new facilities at somewhat decreased gaso-

FIG. 5. Case B—Contact coking + once through catalytic cracking—33,000 bbl a day of 24° API crude.



NOTE: *Figures in parentheses indicate volume percentage on charge to each unit process.*

FIG. 6a. Comparison of operating schemes.

	Unit price $/Bbl	Original case — no coking B/D	Per cent on charge
Crude charge capacity		33,000	100.0
Composite refinery yield			
Premium gasoline, (9# R.V.P. 81.5 M.M, 91.5 RM)		4,815	14.60
Household brand gasoline, (10# R.V.P. 75.5 M.M, 81.5 RM)		7,210	21.85
Total gasoline		12,025	36.45
Mid-barrel distillates		4,650	14.10
Bunker C fuel oil		14,684	44.50
Gas to fuel, (F.O.E.)		*1,815	*5.45
Excess C_4's, (F.O.E.)		.....	.....
Coke products, (F.O.E.)		.....	.....
Product values			
Premium gasoline, $/D	5.46	26,300	
Household brand gasoline, $/D	4.87	35,200	
Mid-barrel distillates, $/D	3.40	15,820	
Bunker C fuel oil, $/D	1.25	18,370	
Gas to fuel (F.O.E.), $/D	1.25	*2,240	
Excess C_4's (F.O.E.), $/D	1.25	.....	
Coke products, $/D	$10/Ton	.....	
Total, $/D		97,940	

Direct operating costs	Capacity, B/D	$/Day
Crude topping	33,000	1,980
Contact coking	.....	.....
Catalytic cracking — reactor charge	7,750	1,705
Thermal cracking — total feed	15,000	1,500
Cracked distillate treating	5,480	1,205
Total		6,390
T.E.L. costs, $/D		1,816
Indirect operating expenses, $/D		1,278
Total expenses, $/D (not incl. fixed charges or crude costs)		9,484
Differential earning, $/D		0
Differential earning, $/Yr		0
Est. cost of new facilities: Contact coking		.....
Catalytic cracking		.....
Gas plant extension		.....
Total (battery limits only)		.....

* Includes excess C_4's.

FIG. 6b. Comparison of operating schemes.

	Unit price $/Bbl	Case A Contact coking + recycle cat. crack. B/D	Per cent on charge
Crude charge capacity		33,000	100.0
Composite refinery yield			
Premium gasoline, (9# R.V.P. 81.5 M.M, 91.5 RM)		7,270	22.03
Household brand gasoline, (10# R.V.P. 75.5 M.M, 81.5 RM)		10,910	33.05
Total gasoline		18,180	55.08
Mid-barrel distillates		4,650	14.10
Bunker C fuel oil		3,740	11.34
Gas to fuel, (F.O.E.)		2,585	7.83
Excess C_4's, (F.O.E.)		2,225	6.74
Coke products, (F.O.E.)		2,201	.....
Product values			
Premium gasoline, $/D	5.46	39,695	
Household brand gasoline, $/D	4.87	53,155	
Mid-barrel distillate, $/D	3.40	15,820	
Bunker C fuel oil, $/D	1.25	4,675	
Gas to fuel (F.O.E.), $/D	1.25	3,240	
Excess C_4's (F.O.E.), $/D	1.25	1,948	
Coke products, $/D	$10/Ton	4,550	
Total, $/D		123,083	

Direct operating costs	Capacity, B/D	$/Day
Crude topping	33,000	1,980
Contact coking	11,200	2,240
Catalytic cracking — reactor charge	33,300	7,320
Thermal cracking — total feed	8,850	885
Cracked distillate treating	2,990	658
Total		13,083
T.E.L. costs, $/D		687
Indirect operating expenses, $/D		2,620
Total expenses, $/D (not incl. fixed charges or crude costs)		16,390
Differential earning, $/D		18,327
Differential earning, $/Yr		6,689,000
Est. cost of new facilities: Contact coking		2,670,000
Catalytic cracking		4,470,000
Gas plant extension		1,700,000
Total (battery limits only)		8,840,000

line yield may be obtained by operating the catalytic cracking on a once-through basis. This was done in Case B shown on Fig. 5. The fuel oil yield is increased about 4½ per cent over the previous case but the total gasoline yield of 51.6 per cent is still considerably higher than the original case without coking.

The gasoline yields in all of the cases could be increased still further by the addition of catalytic polymerization of the unsaturate gases from cracking and by the thermal cracking of heavy catalytic cracking stock, but for purposes of simplification, these additional operating steps were not added to the present studies.

A comparison of the original refinery operation with Cases A and B is shown in Figs. 6a, b, and c. It has been assumed that the refinery originally had capacity for 10,000 bbl of catalytic cracking reactor charge and 15,000 bbl of thermal cracking total feed. The products in the various cases were valued at representative prices and the direct operating costs, tetra-ethyl lead costs and indirect operating expenses were estimated. In this way, a total expense not including fixed charges or crude costs was calculated. The differential earnings of Cases A and B over the original operation are shown to be $6,689,000 per year and $6,208,000 per year respectively. The estimated cost of new facilities within the battery limits for these two cases are 8,840,000 and $5,990,000. Allowing for items of cost not included in the tabulated figures and investment requirements outside of battery limits, which will vary in every refinery situation, it will be seen that the profitability of the coking operation is good.

The comparison in the preceding

Jet Fuel

Aeronautical engineers are engaged in experiments to widen the range of petroleum products which can be used for fueling jet plane engines. Kerosine, the current fuel, represents only about 6 per cent of the products obtained from a barrel of crude oil. Present plans are to use about 50 per cent of the products refined from a barrel of crude, a mixture that would contain all the kerosine and gasoline and about one-fourth of the heating oils in the crude barrel.

FIG. 6c. Comparison of operating schemes.

		Case B Contact coking + once-thru cat. crack.	
		B/D	Per cent on charge
Crude charge capacity		33,000	100.0
Composite refinery yield			
Premium gasoline, (9# R.V.P. 81.5 M.M, 91.5 RM)		6,815	20.65
Household brand gasoline, (10# R.V.P. 75.5 M.M, 81.5 RM)		10,220	30.98
Total gasoline		17,035	51.63
Mid-barrel distillates		4,650	14.10
Bunker C fuel oil		5,185	15.71
Gas to fuel (F.O.E.)		2,490	7.55
Excess C4's (F.O.E.)		1,880	5.70
Coke products, (F.O.E.)		2,201	.....
Product values	Unit price $/Bbl		
Premium gasoline, $/D	5.46	37,210	
Household brand gasoline, $/D	4.87	49,790	
Mid-barrel distillates, $/D	3.40	15,820	
Bunker C fuel oil, $/D	1.25	6,480	
Gas to fuel (F.O.E.), $/D	1.25	3,120	
Excess C4's (F.O.E.), $/D	1.25	1,645	
Coke products, $/D	$10/Ton	4,550	
Total, $/D		118,618	

Direct operating costs	Capacity, B/D	$/Day
Crude topping	33,000	1,980
Contact coking	11,200	2,240
Catalytic cracking — reactor charge	19,140	4,210
Thermal cracking — total feed	12,310	1,230
Cracked distillate treating	3,480	765
Total		10,425
T.E.L. costs, $/D		644
Indirect operating expenses, $/D		2,085
Total expenses, $/D (not incl. fixed charges or crude costs)		13,154
Differential earning, $/D		17,008
Differential earning, $/Yr		6,208,000
Est. cost of new facilities: Contact coking		2,670,000
Catalytic cracking		2,220,000
Gas plant extension		1,100,000
Total (battery limits only)		5,990,000

* Includes excess C4's.

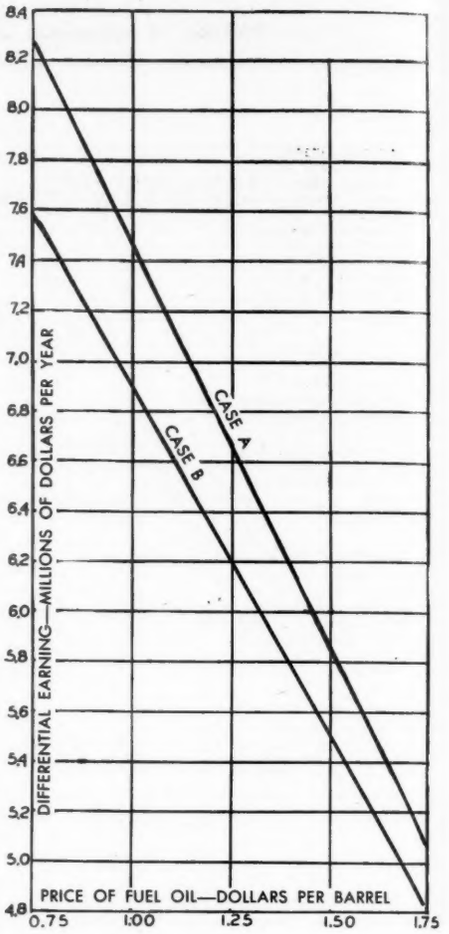


FIG. 7. Differential earning vs price of fuel oil.

tabulation was made on the basis of a Bunker C fuel oil price of $1.25 a barrel with gas and excess B-B valued at fuel oil price on a fuel oil equivalent basis. In order to determine the effect of fuel oil prices on the profitability of coking, these cases were recalculated at several different prices for Bunker C fuel oil with the result shown on Fig. 7, which is a plot showing the differential earnings in millions of dollars per year for Cases A and B at fuel oil prices ranging from $ .75 to $1.75 per barrel.

If these comparison studies had been made with conventional delayed coking instead of contact coking they would still show an advantage for coking but this advantage would be less pronounced. Detailed estimates that have been made show that contact coking costs are only 60 to 75 per cent as much as a delayed coking unit of equivalent capacity. In addition to this, the operating costs for contact coking are lower as the decoking crew is eliminated entirely and the utility demand is decreased by eliminating the high pressure decoking water pump and attendant equipment. As the charge oil in contact coking does not have to be heated to temperatures in the range of 900 to 920 F, the contact coker may be operated on very heavy residual asphalts and pitches that are generally considered inoperable by delayed coking. The contact coking process offers more flexibility in product distribution in that the operating conditions may be varied to obtain a high degree or a very low degree of cracking. When operating at low temperature levels minimum coke production will be obtained and if it is desired to produce some fuel oil products the coke yield still may be further decreased.

If additional thermal or catalytic cracking capacity is not available and new cracking facilities are not to be installed, the contact coker may be designed with a high temperature preheater and the product distribution and quality will then be the same as in delayed coking. At a later date, if more catalytic cracking is installed, the contact coker may be operated at lower oil preheat and higher yields of a near virgin gas oil will then be produced for catalytic cracker charge.

A 100-bbl per day semi-commercial contact coker is now under construction in California and will be in operation in November. This unit has been designed to duplicate as nearly as possible the conditions of the large unit and will demonstrate the process in conclusive fashion.

The author wishes to acknowledge the helpful interest of L. F. Strader of the Richfield Oil Corporation and Fred Hartley of Union Oil Company and their associates. * * *

More Gasoline, Less Crude

Oil refining processes have been advanced by petroleum engineers to the point where today's 20-gallon tankful of automobile gasoline can be obtained from one 42-gallon barrel of crude oil. That same tankful 30 years ago would have required two barrels of crude, while in 1910 refineries had to process four and one-half barrels of oil to squeeze out 20 gallons of gasoline. On top of that, today's gasoline is an infinitely better fuel.

HYDROCARBON ANALYSIS*

Determination of Straight-Chain Hydrocarbons by Urea-Adduct Formation Offers Great Possibilities

W. J. ZIMMERSCHIED,* W. S. HIGLEY,* and A. P. LIEN*

THE quantitative determination of types of hydrocarbons in petroleum stocks has assumed increasing importance as petroleum separation methods have become more refined. Suitable methods of analysis of complex hydrocarbon mixtures have also become necessary in conjunction with the synthetic and semi-synthetic petroleum-refining processes, such as isomerization, polymerization, and hydroforming.

To meet these needs various methods have been developed for the quantitative determination of the major types of hydrocarbons in a petroleum stock. A number of these methods classify naphthenes and paraffins together, or at least do not differentiate between *n*paraffins and *iso*paraffins.[6, 7, 10, 11] Nevertheless, a few analytical methods for determining the actual *n*paraffin content have been described. Rossini et al[5] have analyzed certain hydrocarbon mixtures—utilizing precise measurements of the boiling range, density, and refractive index of narrow cuts obtained from a very efficient fractionation of the sample. Infrared spectrometric[8] analyses of hydrocarbon mixtures including as many as 10 components have been made, but the usual procedure involves a distillation in which the mixture is cut into fractions of rather narrow boiling range. Much labor and time are involved with these methods. Selective adsorption of *n*paraffins on chabazite[2] and on coconut charcoal[1] offers analytical possibilities, but a severe limitation is placed on these materials by the facts that they are active only toward relatively low molecular-weight paraffins and that adsorption capacity is low.

Recent publications[3, 4, 14, 15] have demonstrated that urea possesses the unique property of forming solid complexes with straight-chain organic compounds and of effecting their separation from isomeric mixtures. Of considerable promise as an analytical tool to aid in the analysis of hydrocarbon mixtures containing *n*paraffins is the technique of urea extraction. It is convenient, and it presents distinct advantages over the foregoing methods, for a number of applications. However, in its present state it has not achieved the status of a precise and highly accurate analytical method, and it should be recognized that more development is necessary.

It is the purpose of this paper to outline workable techniques, to illustrate possibilities of the method, and to point out recognized limitations.

For the sake of simplicity, the discussion and illustrations will deal mostly with determination of *n*paraffin hydrocarbons. The reaction and analytical techniques are also applicable to the determination of *n*olefins; for example, in hydrocarbon synthesis products. Further application may be made to linear derivatives of *n*paraffins, such as alcohols, esters, acids, ethers, and halides. In its present state of development the urea analytical technique for hydrocarbons is subject to molecular-weight limitations, viz., to 7 or more carbon atoms for qualitative analysis, and to 14 or more carbon atoms for quantitative analysis.

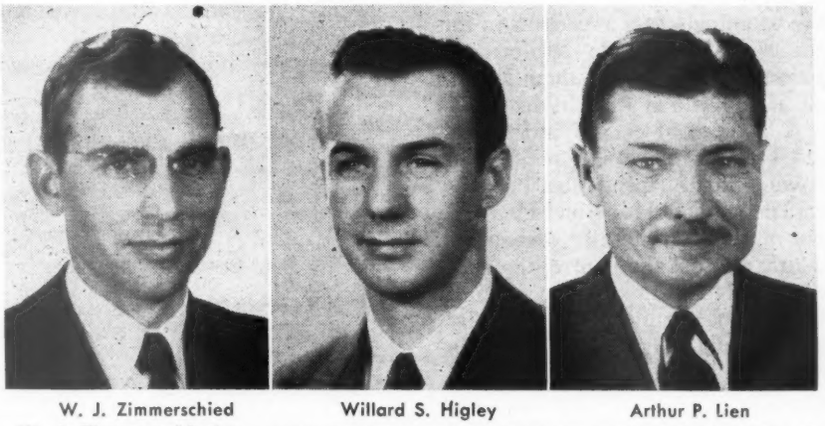
General Procedure

The use of urea as an analytical tool has application in qualitative identification as well as quantitative determination of *n*paraffins. A brief description of the procedure used in each case follows:

Qualitative. The presence of a straight-chain hydrocarbon containing more than six carbon atoms may be determined by addition of a few drops of the sample to a saturated methanol solution of urea. Under such conditions the linear hydrocarbons readily form a precipitate; whereas *iso*paraffins, cycloalkanes, and aromatic hydrocarbons provide no such evidence of adduct formation.

Quantitative. For the quantitative determination of straight-chain hydrocarbons a weighed sample of the hydrocarbon mixture is contacted with an amount of urea corresponding to 1 mole per carbon atom of *n*paraffin present, plus 10 to 15 per cent by weight of methanol based on urea. If the original sample is solid or viscous, it is dissolved in a suitable urea-inert

The Authors



W. J. Zimmerschied | Willard S. Higley | Arthur P. Lien

W. J. Zimmerschied is a graduate of Monmouth College; he received the bachelor of of science degree in chemistry in 1941. He attended the Ohio State University; received the M S degree in 1944; the Ph D in 1946. His studies at Ohio State were interrupted for one year, during which he was employed on a project relating to atomic energy. In 1945, he joined the research staff of Standard Oil Company (Indiana.).

Willard S. Higley, after graduation from junior college in 1941, worked as an analyst in the plastic division of the Dow Chemical Company, Midland, Michigan, until 1942 when he was inducted into the Army and spent 43 months in the Chemical Warfare Service.

After his Army discharge he enrolled at the University of Michigan and received the B S degree in chemistry in 1947 and the M S degree in chemistry in 1948. He joined the research staff of the Standard Oil Company (Indiana) in August, 1948.

Arthur P. Lien obtained the A B degree with a major in chemistry in 1937 from Ottawa University, Kansas. He attended Ohio State University from 1937-1941, where he served as graduate teaching assistant and Fellow of the American Petroleum Institute. Graduate research on synthesis and reactions of alkylaromatics led to the M S degree in 1939 and the Ph D degree in 1941. The same year Lien joined Standard (Indiana) as research chemist.

†Presented at a Symposium on Analytical Research during the 15th Mid-Year Meeting of the American Petroleum Institute's Division of Refining, in the Hotel Cleveland, Cleveland, Ohio, May 1, 1950, under the title "Determination of Straight-Chain Hydrocarbons by Urea-Adduct Formation."

*Standard Oil Company (Indiana), research department, Whiting, Indiana.

solvent such as *iso*pentane, *iso*octane, benzene, or carbon tetrachloride prior to reaction with urea. After 30 min to 45 min of contacting at 25 deg C, the solid product is filtered from the mother liquor by suction, and is washed on the filter with 3 successive portions of cold *iso*pentane (10 to 15 deg C), corresponding roughly to a total of 6 volumes of wash liquid per volume of solid mass. The resulting adduct, plus excess urea, is removed from the filter, and is decomposed by adding sufficient water—approximately an equal weight—to dissolve the urea. The upper liberated hydrocarbon layer is taken up in 3 to 6 volumes of ether, and is separated from the aqueous layer. The ether is evaporated, and the hydrocarbon extract is weighed to give the yield of urea-reactive straight-chain components.

Theoretical Factors

Although the main aspects of the chemistry involved in urea-adduct formation have been discussed broadly in a previous paper,[15] closer examination of certain phases of the reaction is desirable from the standpoint of analytical application.

Activators. The *n*paraffins in petroleum fractions usually fail to form adducts when contacted with urea alone because of the presence of substances which inhibit or prevent adduct formation. For this reason, as well as for others to be described, an activator is required.

In contrast to petroleum stocks, pure *n*paraffins react with urea in the absence of an activator; reaction in this case seems to initiate between the *n*paraffin and the small quantities of urea dissolved in the hydrocarbon phase. The use of an activator or solvent—such as methanol, ethanol, or acetone—greatly accelerates the reaction. The methanol is believed to bring about mutual solution of hydrocarbon and urea so that the controlling reaction of adduct formation occurs in a homogeneous liquid phase. The following equilibria are presumably involved:

$$\text{Urea}_{(s)} \rightleftharpoons \text{Urea}_{(d)} \quad (1)$$

$$n\text{Paraffin}_{(l)} \rightleftharpoons n\text{Paraffin}_{(d)} \quad (2)$$

$$\text{Urea}_{(d)} + n\text{Paraffin}_{(d)} \rightleftharpoons \text{Adduct}_{(s)} \quad (3)$$

$$\text{Adduct}_{(d)} \rightleftharpoons \text{Adduct}_{(s)} \quad (4)$$

where: subscripts (*s*), (*l*), and (*d*) refer to solid, liquid, and dissolved phases, respectively. The controlling equilibrium for adduct formation involves equilibrium (3) in the dissolved, or homogeneous-solution, phase.

The following equilibrium constant, therefore, applies:

$$K_{(\text{reaction})} = \frac{[\text{adduct}_{(d)}]}{[\text{urea}_{(d)}]\,[n\text{paraffin}_{(d)}]}$$

where: the bracketed expressions represent the concentrations or, more correctly, the activities of the respective materials.

The important consideration for quantitative determination of linear compounds is the attainment of conditions that will drive the series of equilibria in equations (1), (2), (3), and (4) as far to the right as possible. For the reaction step (3), this involves as high a value as possible for *K*. The activator plays on important rôle in this respect, in that it brings the urea and the *n*paraffin into homogeneous solution, as shown in equations (1) and (2)—so that the adduct-forming reaction [equation (3)] may proceed at an optimum rate. The nature and concentration of the activator must be such that the equilibrium in equation (4) is maintained on the side of precipitated solid adduct. A number of other factors, discussed hereinafter, must also be considered in order to arrive at the desired maximum clean-up of urea-reactive material.

Molecular Weight. Stability of urea adducts varies directly as a function of the moleculer weight of the adducted compound. With increasing molecular weight, the equilibrium in equation (3) is progressively displaced farther to the right, and the value of $K_{(\text{reaction})}$ becomes progressively larger; with hydrocarbons of 18 or more carbon atoms, the adduct is very stable. Therefore, the determination of intermediate molecular-weight linear compounds is less accurate, and must be conducted under special conditions to attain reasonably dependable results.

Temperature. It has been demonstrated that most urea adducts tend to dissociate; i.e., the equilibrium of equation (3) is displaced to the left—at temperatures appreciably above 25 deg C[15]; the value of $K_{(\text{reaction})}$ is decreased with increasing temperature. In most cases room temperature is adequate for high recovery and convenient handling, and the rate of formation is reasonably rapid.

Concentration of Urea. The urea to carbon-atom ratio of adducts is approximately 3 to 4.[15, 13] To insure that all normal hydrocarbons present will react, sufficient excess urea over this ratio is necessary to maintain a saturated dissolved phase throughout the reaction period.

Dilution. Addition of a hydrocarbon solvent to the urea-reaction system has the effect of displacing the equilibrium in equation (3) to the left. This behavior has important implications in the analytical procedure, inasmuch as it is necessary to remove occluded mother liquor from the adduct with a minimum amount of dissociation. Perhaps the largest factor causing erratic quantitative results may be attributed to adduct dissociation during the washing step. For this reason it has been found desirable to remove most of the occluded mother liquor by suction filtration, and to carry out the washing procedure at lower than room temperature, and with a minimum of urea-inert wash liquid.

Precision and Accuracy

For the purpose of determining the precision and accuracy of the quantitative method, series of runs were carried out on known blends of pure dodecane, tetradecane, and hexade-

TABLE 1. Extraction of known *n*paraffin blends with urea.

Temperature: 25 deg C
*n*Paraffins: 10 g in 90-g diluent
Urea: 45 g (1.06 moles per carbon atom)
Methanol: 4.5 g (10 per cent by weight on urea)
Wash: 6 volumes per volume of solid

Feed Decalin solution	Run no.	*n*Paraffin extract: Grams	*n*Paraffin extract: n_D^{20}	*n*Paraffin extract: Purity (Per cent by volume)	Per cent by weight of *n*paraffin based on: Crude extract	Per cent by weight of *n*paraffin based on: 100 per cent purity
nC_{12} (n_D^{20}, 1.4215)	1	7.2	1.4216	99.8	72	72
	2	7.2	1.4218	99.4	72	72
	3	7.0	1.4218	99.4	70	70
nC_{14} (n_D^{20}, 1.4288)	4	9.9	1.4320	93	99	92
	5	9.8	1.4317	94	98	92
nC_{16} (n_D^{20}, 1.4347)	6	9.8	1.4362	96	98	94
	7	10.4	1.4386	92	104	96
	8	9.8	1.4373	94	98	92
Methylnaphthalene solution						
nC_{14} (n_D^{20}, 1.4288)	9	13.1	1.4702	78	131	95
Extract from run No. 9	9a	....	1.4302	99.4	...	..
nC_{14} (n_D^{20}, 1.4288)	10	11.6	1.4569	85	116	93
Extract from run No. 10	10a	....	1.4296	99.6	...	..

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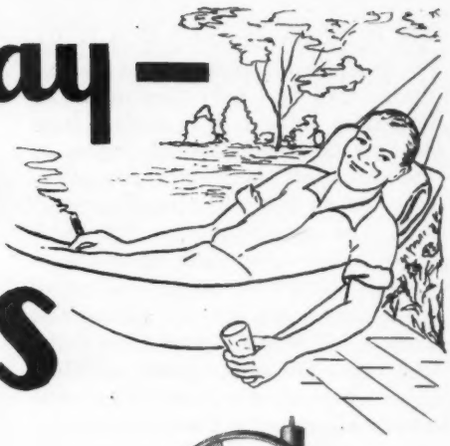

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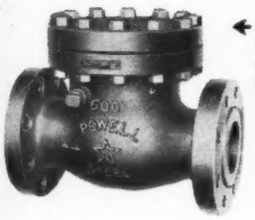


← **Fig. 6061**—Class 600-pound Cast Steel Swing Check Valve with flanged ends and bolted cap. Disc has ample lift to permit full, straightway, unobstructed flow through valve body.

← **Fig. 1375**—200-pound Bronze Gate Valve with screwed ends, inside screw rising stem, union bonnet and renewable, wear-resisting "Powellium" nickel-bronze seat rings and disc.

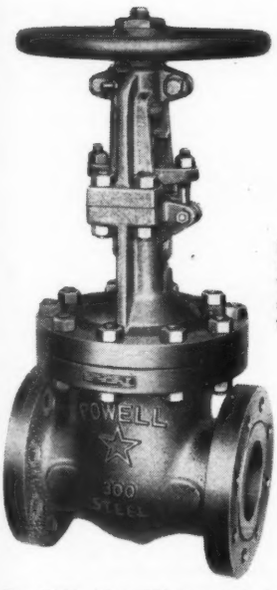


Fig. 3003—Class 300-pound Cast Steel Gate Valve with flanged ends, outside screw rising stem, bolted flanged yoke and tapered solid wedge.

Fig. 1460 — Iron Body Bronze Mounted "Master Pilot" Gate Valve with screwed ends, rising stem, bolted flanged bonnet and tapered solid wedge. →

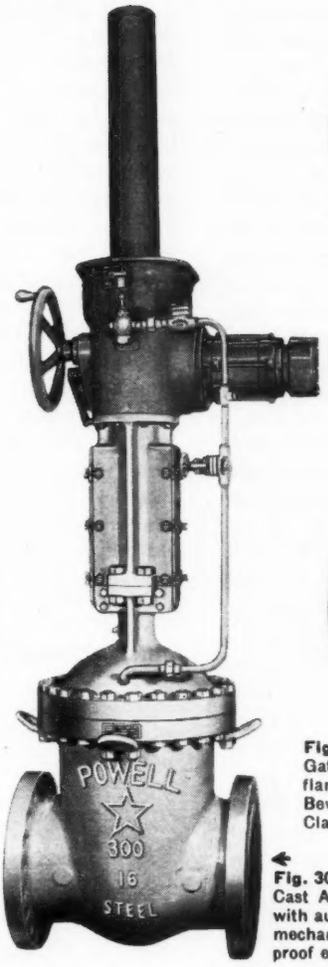
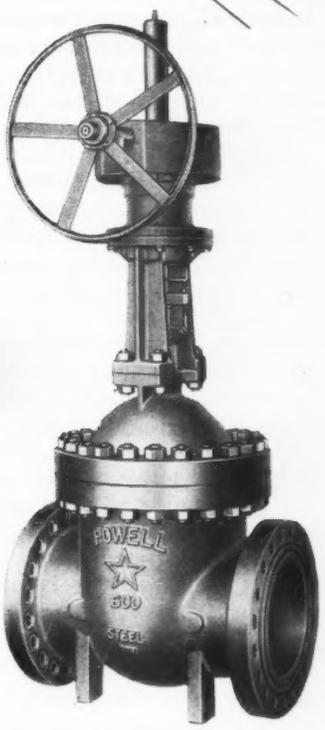


Fig. 6079 — Class 600-pound Cast Steel Gate Valve for Pipe Line Service. Has flanged ends and bolted flanged bonnet. Bevel gear operated. Also available in Classes 150, 300, and 400 pounds.

← **Fig. 3023**—Class 300-pound Cast Alloy Steel Gate Valve with automatic steam sealing mechanism. Has explosion proof electric motor operator.



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cane in decalin solvent (n_D^{20}, 1.4770). The quantities of material and the conditions used were held constant, as indicated in Table 1. It is evident from the data obtained that the degree of reproducibility, both on purity of extract and on per cent *n*paraffin recovered, was satisfactory on the check determinations for each *n*paraffin, as shown in runs 1 through 8.

The purity of recovered extract was in excess of 99 per cent for the dodecane runs. The lower purity of 93 to 96 per cent in the tetradecane and hexadecane runs indicates the occlusion of some of the decalin diluent with the recovered extract. The indicated per cent *n*tetradecane by urea analysis represents 98 to 99 per cent of that originally present when based on crude extract, or 92 per cent when correction is made for decalin impurity. With hexadecane, 98 to 104 per cent of the *n*paraffin is accounted for, based on crude extract; 92 to 96 per cent, when correction is made for decalin contaminant. Further experiments have shown that the decalin impurity may be essentially completely removed by more thorough washing of the adduct, although more of the *n*paraffin is also lost. For example, a run was carried out on hexadecane identical to those reported in Table 1, but involving twice as much wash liquid. The total extract yield was 92 per cent as compared with 98 to 104 per cent, but the extract was 99.3 per cent pure (n_D^{20}, 1.4350) as compared with 92 to 96 per cent purity in the runs with less washing. Greater accuracy may be possible when larger quantities of sample are used.

All the analyses in the case of dodecane are consistently 28 to 30 per cent low, although the results obtained in runs 1, 2, and 3 were obtained by 3 different operators. This low accuracy has been traced to dissociation in the washing step. Refractive-index analyses of the raffinates indicated that the urea-extraction step had removed 98 per cent of the *n*paraffin; examination of the *iso*pentane washes disclosed the presence of the missing 26 to 28 per cent dodecane. It appears, therefore, that extraction of *n*paraffins was essentially complete in all cases in Table 1, but the stability of the adducts toward washing rose sharply in going from 12-carbon to 14-carbon *n*paraffins.

Interfering Substances

Although a high-purity extract was obtained in all cases involving blends of *n*dodecane in decalin, a small amount of decalin contamination occurred with tetradecane and hexadecane. A much higher degree of contamination occurred when methylnaphthalene (n_D^{20}, 1.6128) was used as the diluent, as shown by the high index and the yields greater than 100 per cent of crude extract in runs 8 and 9 of Table 1. When the impure extract originally obtained in each case was dissolved in *iso*pentane and re-extracted with urea, an extract of markedly higher impurity was obtained, as in runs 9a and 10a. When present in large amounts, the aromatic hydrocarbon apparently was adsorbed by the solid phase, and was not removed during the washing of the first urea adduct.

This phenomenon of adsorption of impurities was further demonstrated by a series of runs on West Texas gas oil. As shown in Table 2, the intial extracts (in runs 1 and 2) were excessively high in index. Re-extraction in each case (in runs 1a and 2a) markedly reduced the index, as well as the yield of *n*paraffin. Reproducibility was satisfactory.

For quantitative determination of the *n*paraffin content of most petroleum stocks, it is necessary—in view of the foregoing—to guard against contamination, especially by aromatics. This end may be achieved by retreatment of the extract with additional urea, as has been demonstrated. Equally effective is the removal of aromatics from the stock prior to urea extraction. The use of each of these methods is described in the following section.

Analytical Applications to Petroleum Stocks

Several detailed examples will serve to illustrate the applicability of the urea-extraction technique to the quantitative determination and separation of the *n*paraffins present in various refinery stocks.

Narrow-Fraction Virgin Naphtha. An 11-carbon cut, boiling at 128 to 130 deg C per 100 mm, after silica-gel treatment to remove aromatics resulted in a product of n_D^{20}, 1.4242, as compared with 1.4307 for the original cut. The aromatic-free stock thus obtained was subjected to urea treatment, with the results shown in Table 3. In run 1, where a deficiency of urea was used, extraction of *n*paraffins was incomplete. In runs 2 and 3, with excess urea, a higher degree of extraction was obtained. However, in view of the results on dodecane, the indicated per cent undecane is probably low, because of dissociation of adduct in the washing step. The refractive index of the extract, quite close to that of pure undecane, shows little contamination by other materials.

Broad-Cut Catalytic Cycle Oil. A 213- to 288-deg-C cut from light catalytic cycle oil (3.0 kg) was stirred with 1.0

TABLE 2. Extraction of West Texas virgin gas oils with urea.

Run No.	Gas oil (Grams)	Urea (Grams)	Methanol (Grams)	Extract		
				Weight (Grams)	Per Cent of Feed	n_D^{20}
1	1,380	720	40	292	21.2	1.4528
1a	Extract from 1	720	40	193	14.0	1.4452
2	345	180	10	66	19.1	1.4483
2a	Extract from 3	240	12	48	13.8	1.4390

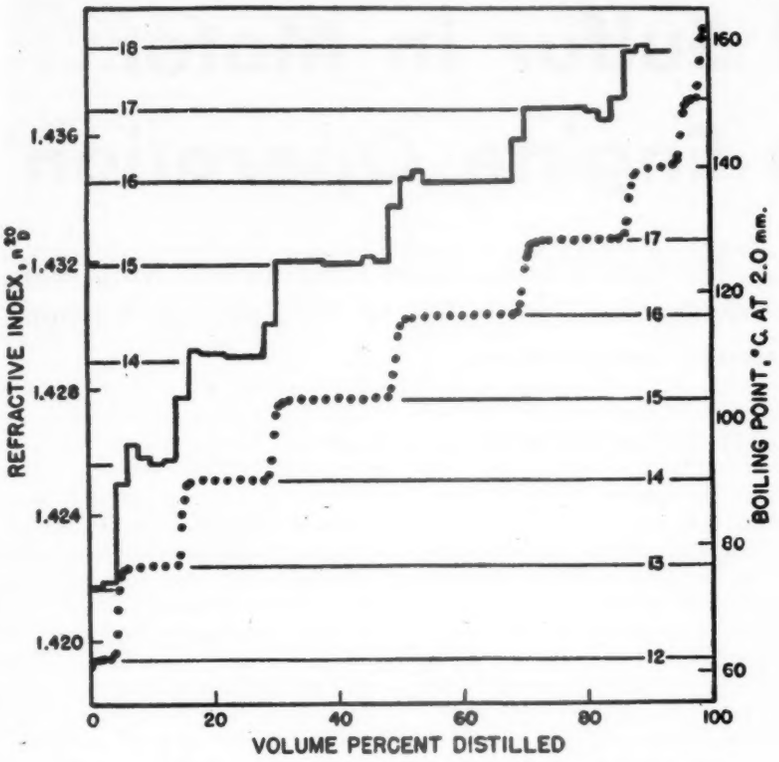
TABLE 3. Extraction of aromatic-free C_{11} fraction with urea.

Run No.	Charge (Grams)	Urea (Grams)	Methanol (Grams)	Extract		
				Grams	Per Cent of Charge	n_D^{20}
1	39	60	96	14	35	1.4178
2	52	160	181	25	48	1.4172
3	52	300	316	25	48	1.4183

[a] *n*Undecane — n_D^{20}, 1.4173.

TABLE 4. Extraction of light catalytic cycle stock with urea.

	Grams	Per Cent by Weight	n_D^{20}
Initial petroleum fraction	3,000	100.0	1.4977
Inert urea reject	2,700	90.0	1.5045
Crude *n*paraffin extract:	(300)	(10.0)	.....
First *n*paraffin fraction	186	6.2	1.4342
Rich reject	(113)	(3.8)	.....
Second *n*paraffin fraction	64	2.1	1.4342
Intermediate reject	(52)	(1.7)	1.4399
Third *n*paraffin fraction	28	0.9	1.4305
Inert urea reject	24	0.8	1.4500
Combined reprocessed *n*paraffin fractions	(275)	(9.2)	(1.4339)
Adsorbed on silica gel	3	0.1	1.4550
Silica-gel-treated *n*paraffin	(272)	(9.1)	1.4328
Total of final fractions (balance)	3,005	100.1	.....



The horizontal lines show the known[12] refractive indices and boiling points of the successive nparaffins of carbon number indicated by the numerals.

FIG. 1. Fractionation of *n*paraffins from a petroleum distillate.

kg of urea moistened with 200 g of methanol. After having been washed with 1.5 liters of 2,2,4-trimethylpentane, the adduct was decomposed in 3 liters of water. Recovery of crude *n*paraffin extract represented a 10-per-cent preliminary yield. Retreatment of the unreacted oil with urea gave no evidence of further adduct formation, an indication of essentially complete extraction. Retreatment of the crude extract, however, resulted in further purification; 3 successive treatments with urea were carried out, as summarized in Table 4. About 0.8 per cent of the original oil was rejected in this way. After a trace of non-paraffinic material had been removed with silica gel, 9.1 per cent of the oil was recovered as *n*paraffin. Fractionation of this product through a packed column of 100 theoretical plates provided the data plotted in Fig. 1. Comparison with the boiling points and refractive indices[15] of known *n*paraffins showed little else was present except the *n*paraffins from dodecane through nonadecane.

Heavy Petroleum Stocks and Natural Waxes. The straight-chain content of a number of petroleum fractions and waxes was determined by the urea technique. The stock was dissolved in a urea-inert solvent, as indicated in Table 5; sufficient solvent was used in each case to provide a clear non-viscous solution. After 60 min of contact with the indicated amount of urea-methanol, the solid phase was filtered and washed free of non-reactive material with additional quantities of the original solvent.

The first five runs presented show typical urea extractions for various petroleum fractions. In all of the examples the melting points of the straight-chain extracts isolated from the solid products were higher than those of the raffinates. In the case of candellila wax, the urea adduct was so firmly held that hot-water washing failed to regenerate the extracted material. In this case the adduct was decomposed in the following manner:

A 28.3-g sample of the candellila-wax adduct was added to 700 ml of water and 300 ml of toluene in a metal stirring bomb. The mixture was agitated at 132 deg C for 3 hours under 10 atmospheres of nitrogen pressure. The toluene layer containing the regenerated wax was separated and washed three times with water.

Evaporation of the toluene left 5.6 g of candellila-wax extract: Melting point, 68 deg C.

Conclusion

Although subject to limitations and in need of further development, the urea-extraction technique provides a useful tool to simplify the task of analyzing complex petroleum mixtures. Its value lies not only in the qualitative and quantitative determination of *n*hydrocarbons as a class, but also in the physical segregation of the straight-chain derivatives. It is, therefore, a valuable technique for use in combination with existing methods of analysis. The general techniques described may also be applied to other straight-chain organic molecules, such as alcohols, esters, acids, ethers, and halides.

Acknowledgment

The authors are indebted to R. F. Marschner and A. W. Weitkamp for their interest and assistance in this work.

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* * *

TABLE 5. Extraction of heavy petroleum stocks and natural waxes with urea.

Feed	Grams	Solvent	Urea (Grams)	Methanol (Grams)	Straight chain (Per Cent)	Melting point (deg C) Feed	Raffinate	Extract
1. Reduced crude	199	Benzene	150	40	6	..	..	53
2. Lubricating-oil distillate	200	*Iso*octane	150	24	11	..	..	60
3. Petrolatum base	300	*Iso*octane	200	40	13	59	52	70
4. Paraffin distillate	200	*Iso*octane	200	48	16	..	..	38
5. Slack wax	50	*Iso*octane	183	12	57	40	..	49
6. Candellila wax	103	Benzene	77	218	54	65	..	68
7. Beeswax	179	Benzene	150	64	58	62	51	66
8. Ozocerite wax	183	Benzene	150	48	87	85	Tacky	86

Effects of Sulfur in Motor Gasoline on Engine Operation*

Influence of Sulfur Up to 0.3 Per Cent Varies From Pronounced Ring and Cylinder Wear Under Severe Operating Conditions to No Effect at Normal Engine Temperature.

R. E. JEFFREY[1], J. B. DUCKWORTH[2], E. J. GAY[3]

THIS is a report of a cooperative investigation by the petroleum and automotive industries and several fleet owners. This investigation was directed toward acquiring factual data regarding the effect, on engines, of sulfur in motor gasoline. The scope of the program was limited to the technical aspects of sulfur in motor gasoline, and did not include an evaluation of economic considerations which are a part of the broad over-all problem.

Background

The increasing utilization of high sulfur crudes to supplement crude supply during and following World War II, has focused attention on the possible effect of sulfur in motor fuel on engine wear, corrosion, deposits and other factors affecting engine life. Extensive work on these problems had not been conducted since the early 1920's, largely because since that time, improvements in engine design, particularly the almost universal use of crankcase ventilation and thermostatic control of engine jacket temperature, have reduced the incidence of trouble from sulfur in motor gasoline to a point where it is not currently recognized as an acute problem. This is further borne out by the satisfactory operation experience on the West Coast of the United States, where moderately high sulfur levels in gasoline have been used for many years. Also, certain surveys made prior to the war, did not tie increased sales of pertinent engine and exhaust system parts to the areas where higher sulfur fuels were sold. It was recognized, however, that adequate up-to-date technical information was not presently available, and at a meeting of the executive committee of the Coordinating Research Council Board of Directors, the petroleum members proposed that factual data on this subject would be desirable. The problem was assigned to the Motor Fuels Division of the Coordinating Fuel Research Committee on September 17, 1945, and a group on sulfur in motor gasoline was organized to handle the project.

Laboratory Engine Tests

Because of the complexity of the overall problem, it was decided to conduct relatively inexpensive laboratory dynamometer tests. These tests would serve to indicate the conditions under which sulfur might affect engine performance and further, would aid in the selection of fuels for field service tests which were to be run at a later date. Dynamometer tests consisted of various single cylinder and multicylinder engine tests, run under a wide variety of test conditions, ranging from high to low operating temperatures and from continuous to cyclic or intermittent operation.

Approximately 100 laboratory engine tests covering at least 3800 test hours, when compiled and analyzed, showed that cylinder bore and piston ring wear increased with higher sulfur content of the gasoline. The Laboratory Test Panel, recognizing that normal field operating conditions and geographic location might produce results differing from laboratory dynamometer tests, recommended the adoption of a full scale field service test.

The Laboratory Test Panel recommended field service tests using a fuel containing 0.25 per cent to 0.30 per cent sulfur for the higher sulfur value and a fuel of less than 0.10 per cent for the lower sulfur value. This range was chosen so as to bracket commercial gasoline sulfur contents that would normally be expected to be distributed in this country over the next several years. At present, most commercial gasolines are substantially below this higher value. The panel further recommended that the fuel of lower sulfur value used for tests on the West Coast could be 0.15 per cent or less.

Engine Field Service Tests

The recommendation of the Laboratory Test Panel was accepted and in the summer of 1947 a Field Test Panel was organized to initiate a practical field service test program. The CFR-MFD Group on Sulfur in Motor Gasoline recognized that any one field service test program would not furnish a complete and final appraisal of the problem. These tests, however, would help sort the problem into definite categories where sulfur in gasoline may or may not be a problem and would provide guidance for future work.

TABLE 1. Summary of engine cylinder and ring wear.

Fleet	Vehicle type	Test fuels weight in per cent of sulfur		Cyl. bore wear at top ring corrected for mileage*		Top ring wear corrected for mileage*		Per cent increase in wear high S over low S corrected for mileage†	
		Low S	High S	Low S	High S	Low S	High S	Bore	Rings
1	A	0.114	0.256	.0044″	.0038″	.0044″	.0050″	—14	14
2	B	0.091	0.281	.00168″	.00137″	.0097″	.00963″	—18	— 2
7	F	0.132	0.264	.0040″	.0044″	.0192″	.0203″	10	6
7	HA	0.132	0.264	.0090″	.0051″	.0278″	.0299″	—43	7
7	J	0.132	0.264	.0023″	.0023″	.021″	.027″	0	29

* Average actual wear divided by average actual miles and multiplied by 10,000 to give 10,000 mile units.

† Per cent change = $\frac{\text{Wear H.S. (per unit mile)} - \text{Wear L.S. (per unit mile)}}{\text{Wear L.S. (per unit mile)}}$

*Presented at the Society of Automotive Engineers, summer meeting, French Lick Springs Hotel, French Lick, Indiana, June 4-9, 1950.

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[3]Coordinator, Field Service Tests on Sulfur in Motor Gasoline and Consultant, Detroit, Michigan.

After conferences with many fleet owners in various parts of the country, seven fleets (62 vehicles) were selected. These fleets represented a wide variety of equipment from passenger cars to heavy trucks, in services ranging from light duty city delivery, to over-the-road heavy duty. The test locations covered a considerable range of ambient air temperatures. A more complete account of each fleet is shown in Table I.

During early conferences on the conduct of the field test program, representatives of Ford, Chevrolet, and Chrysler agreed to supply new test engines for the fleets using their make of vehicle. They also agreed to undertake the task of measuring these same engines after their removal at the end of the test. The American Petroleum Institute agreed to assume an estimated expense of approximately $50,000.00 for the direct cost of the test to the Coordinating Research Council. The oil companies were to furnish project engineers and other personnel for the technical surveillance of the test vehicles.

Original plans called for the supply of a naturally occurring high sulfur gasoline to all fleets. In selecting the test fleets it became apparent that locations ranging from central Pennsylvania to the West Coast would necessitate shipping from the West Coast, and storing, approximately 200,000 gal of gasoline. This presented a difficult problem of supply as well as an item of very considerable expense. As a result of this, consideration was given to the work of the Laboratory Test Panel on various sulfur compounds. This work showed that a number of sulfur compounds, when added to a given fuel, gave approximately the same results from the standpoint of cylinder bore and piston ring wear as was obtained with fuels containing an equal amount of natural sulfur. A further check test was made by one of the oil company research laboratories using disulphide oil as a means of raising the sulfur content of the test gasoline. This test confirmed the earlier results and upon the recommendation of the Fuels Panel, the Sulfur Group agreed to use disulphide oil as a means of obtaining higher sulfur values in the gasoline.

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More than four and one-half million U. S. homes are kept warm with central-heating oil furnaces. In addition, more than six million oil-burning space heaters are now in use. Such equipment was rarely used a quarter-century ago.

The gasoline normally furnished the fleet was used as the control fuel. To this fuel a sufficient amount of disulphide oil was added to obtain the desired level of 0.25 to 0.30 per cent sulfur. This gave the additional advantage of having the base stock, tetraethyl lead content and octane number (prior to the addition of the disulphide oil) the same for both fuels. There was one exception to this procedure. One West Coast fleet was provided with a naturally occurring high sulfur gasoline. This was done to give a direct comparison with another fleet in the Mid-West, in similar service, but using gasoline with disulphide oil added. In most fleets, extra tankage and another dispensing pump were provided to handle the special fuel.

No attempt was made to place special crankcase lubricating oils in these various fleets, since it was felt that variables other than the sulfur content of the gasoline should not be introduced at this time. It was also not desirable to risk the psychological problems that might arise, which could be blamed on the change of oil type. Each fleet operator was asked to agree to continue using the same brand of oil throughout the year's test duration. In one fleet two types of oil were already in use, and in that case the sulfur test vehicles were split half and half between the two oils; one oil was a regular grade, the other oil was a heavy duty grade.

As shown in Table I, new engines were installed in four fleets. In the fifth fleet the trucks were new at the start of the tests so that these engines could be considered as new engines. The engines from the two remaining fleets were disassembled, rebuilt and measured before the start of the test. New mufflers were installed on all vehicles. A project engineer from the oil company supplying the fuel was assigned to each test fleet. It was his duty to provide technical surveillance of the test, following procedures set down by the Field Test Panel. No attempt was made to change the operator's methods of running his fleet, since this would then take the test out of the category of a practical field operation. This procedure developed certain disadvantages which will be discussed later in this paper.

Periodic fuel and used oil samples were checked by the project engineer's parent company. Also, used oil samples were sent to the Shell Laboratories on the West Coast for a reference check of all oils by one laboratory. Just prior to the start of the tests the Engine Sludge and Varnish Group of the Motor Fuels Division suggested that this sulfur field test program presented an excellent opportunity to obtain comparative data between laboratory and field tests on engine deposits. Accordingly, arrangements were made to send sufficient supplies of gasoline and lubricating oils to several laboratories for FL-2 and L-4 tests.

Actual field tests started with some vehicles in late October, 1947. All tests were in operation by February, 1948 and were completed by the late spring of 1949. Prior to the end of the tests, two new panels within the sulfur group were formed. One of these was the Engine Inspection Panel and the other was the Engine Sludge and Varnish Rating Panel. Inspection procedures were set up by each panel and these procedures were, in general, followed for each fleet. All engines (from 4 fleets) furnished by Chevrolet, Chrysler, and Ford were removed from the test vehicles and shipped back to the engineering departments of these companies for inspection and measurements. The engines from the other three fleets were removed and inspected at/or near the fleet location. Engineers from the manufacturers were able to view all engines except one fleet on the West Coast. In most cases at least two men from the Engine Inspection Panel were able to view all of the test engines. Through a very fortunate arrangement all fleets with the exception of one West Coast fleet had at least one man from the Sludge and Varnish Panel available to help start the rating of the engines. All the engines that were sent back to Detroit for inspection and measurements were thoroughly rated for sludge and varnish by the same two men in order to establish uniformity in standards of rating. Engines that came back to the manufacturer were measured and rated in accordance with standards of accuracy normally used by the manufacturer. Likewise, engines examined in the field were carefully measured by skilled personnel. In order to achieve more complete coordination of data, the project engineer from each of the fleets using Chrysler, Ford, and Chevrolet engines were present at the respective manufacturer's plants during the time the engines were being inspected and measured.

The National Research Laboratories of Canada cooperated with CRC on this problem and during 1946-48 carried out a service test at the Canadian Army proving grounds using military vehicles. Operation under stop and go driving conditions produced no significant difference between fuels containing approximately 0.05 per cent and 0.30 per cent sulfur. The cylinder bore wear observed in the Canadian tests, however, did not exceed 0.001 in. after 2300 miles op-

eration on either low or high sulfur gasoline.

After the inspections were completed, the entire file of data on the seven test fleets, representing many hundreds of pages of observations, was turned over to a seven-man analysis panel. This panel was charged with the responsibility of preparing the final report on the tests for the CFR Committee.

TABLE 2. Summary of engine cylinder and ring wear.

Fleet	Vehicle type	Test fuels weight in per cent of sulfur		Cyl bore wear at top ring corrected for mileage*		Top ring wear corrected for mileage*		Per cent increase in wear high S over low S corrected for mileage†	
		Low S	High S	Low S	High S	Low S	High S	Bore	Rings
3	C	0.063	0.267	.0020″	.0042″	.0292″	.0490″	110	68
4	D	0.066	0.267	.00165″	.00296″	.0093″	.0196″	80	111
6	D	0.140	0.290	.0032″	.0056″	.0201″	.0313″	75	56
6	G	0.140	0.290	.0065″	.0122″	.0614″	.0804″	88	31
7	H	0.132	0.264	.0107″	.0177″	.0478″	.0688″	65	44
7	I	0.132	0.264	.0054″	.0120″	.0411″	.0786″	123	92

* Average actual wear divided by average actual miles and multiplied by 10,000 to give 10,000 mile units.

† Per cent change = $\frac{\text{Wear H.S. (per unit mile)} - \text{Wear L.S. (per unit mile)}}{\text{Wear L.S. (per unit mile)}}$

Results

Sixty-two vehicles completed field service tests at seven test sites during the period October, 1947 to June, 1949. Two motor gasoline sulfur levels of 0.056 per cent-0.140 per cent and 0.25 per cent-0.30 per cent were compared in regard to engine wear and cleanliness. A total of 1,501,698 test miles was accumulated in services ranging from light duty to intermittent duty to continuous heavy duty. From these tests the following results may be of major interest:

1. Twenty vehicles in three fleets representing four types of engines used in a heavy duty or moderate duty continuous service such as over-the-road trucks, urban bus service or medium bus service showed essentially no difference in wear for gasoline sulfur contents within the limits prescribed by the test procedure and as shown in Table I. No inter-city bus service test was conducted, but based on the results of the over-the-road truck service it may be reasonable to assume that the same result would apply.

2. Thirty-four vehicles in four fleets representing five types of engines, in light duty intermittent service with many stops and starts or idle periods per day produced consistent differences in wear within the sulfur limits prescribed by the test procedure and as shown in Table 2. Typical services for these vehicles are city delivery routes such as bread and parcel delivery, light repair or trouble shooter trucks for gas, telephone and electric utilities, supervisor's cars, etc.

3. Eight vehicles in one fleet engaged in typical medium duty intermittent delivery service, door-to-door, showed a marked increase in wear. In this fleet wherein the low sulfur fuel was 0.056 per cent and the high sulfur fuel 0.269 per cent, and wherein a regular grade of oil was used, wear for the high sulfur engines had progressed to the level of requiring an overhaul. See Table 3.

The use of a heavy duty crankcase oil (REO-37) in this fleet produced a 50 per cent reduction in cylinder wear in vehicles operated on the low sulfur fuel, but did not appreciably reduce cylinder wear in the high sulfur vehicles. Cylinder wear for both oils and the *high sulfur fuel* was five to six thousandths (0.005 to 0.006 in.). However, wear when using the (REO-29) regular oil and the *low sulfur fuel* was three thousandths (0.003 in.). With the *low sulfur fuel* and the (REO-37) heavy duty oil the wear was about one and one-half thousandths (0.0015 in.), or approximately one-half the amount of wear as obtained with the regular oil.

4. In the same fleet (No. 5) wherein a heavy duty oil (REO-37) was compared with a regular oil (REO-29) it was noted that crankcase deposits and oil ring groove deposits were reduced for both high and low sulfur vehicles by the heavy duty oil.

5. In a comparison of one fleet (West Coast) using a naturally occurring high sulfur gasoline against one other fleet (Mid-West City) using the same vehicles in the same type of service and using a gasoline with disulphide oil added, wear results were substanially equivalent. This confirms previous tests made during the laboratory test phase.

6. Valve operation and valve life were not adversely affected by high sulfur fuel. Three low sulfur vehicles in one heavy duty fleet were overhauled during the test period because of sticking valves.

7. Muffler life and exhaust system corrosion were not adversely affected by high sulfur fuel.

8. In all but one of the seven fleets, there was little or no effect of high sulfur on engines varnish and sludge deposits. This other fleet showed differences of 7 to 10 points (out of a possible 100) in favor of the low sulfur fuel.

9. Laboratory dynamometer FL-2 tests qualitatively reflect the effects of high sulfur on cylinder and ring wear in light duty intermittent service, but L-4 tests do not reflect wear in medium to heavy duty service.

10. Based on two fleets in light duty-intermittent service, and within the range of atmospheric conditions and temperatures prevailing during the test period, (the actual mean minimum air temperatures were 18 F and 45 F.) there was no apparent influence of ambient air temperatures or geographic location on differences in engine wear between high and low sulfur fuels.

11. The test data do not permit separation of the effect of engine design on the difference in wear due to sulfur because of the influence of type of service or duty. In one fleet, where two types of vehicles were employed the percentages increase in wear with high sulfur fuel were not significantly different. However, the absolute rate of wear in one type of vehicle was approximately twice as high as that in the other with both high and low sulfur fuels. The maximum difference in bore wear was .0016 in. and the test mileage was 2900-3400.

Application of Experience to Any Future Field Service Tests

This field service test program has shown that it is possible to conduct wide scale field tests on a cooperative basis. The practical aspects of these tests are of real value; since as yet there appears to be no good substitute for letting the engine say what it likes; nor is there an electronic device that duplicates all the variables of a driver's foot on the accelerator pedal. Lessons were learned which would bear repeating herein.

TABLE 3. Summary of engine cylinder and ring wear.

Fleet	Vehicle type	Test fuels weight in per cent of sulfur		Cyl. bore wear at top ring corrected for mileage*		Top ring wear corrected for mileage*		Per cent increase in wear high S over low S corrected for mileage†	
		Low S	High S	Low S	High S	Low S	High S	Bore	Rings
5 regular oil	E	0.056	0.269	.0030″	.0065″	.0126″	.0239″	117	90
5 H.D. oil	E	0.056	0.269	.0013″	.0052″	.0082″	.0173″	300	111

* Average actual wear divided by average actual miles and multiplied by 10,000 to give 10,000 mile units.

† Per cent change = $\frac{\text{Wear H.S. (per unit mile)} - \text{Wear L.S. (per unit mile)}}{\text{Wear L.S. (per unit mile)}}$

The oil consumption figures obtained for many of the fleets were not adequate. It is not practical for an operator to carefully drain and weigh the oil at each drain period and to also weigh the new fill of oil. It has been suggested that calibrated dip sticks be used in any future tests. Maintenance crews would then be instructed about overfilling at a drain period and when adding make-up oil. It would also be necessary to request the fleet to add oil to bring the crankcase to the "full" mark before the oil was drained. In this way a reasonably accurate figure of total oil added between drain periods would be obtained. The fleet would have to be reimbursed for the extra oil used at the drain period, but this amount would be small, in return for the improved accuracy of the data.

It still appears that it is best not to have an engineer on the property at all times. When this is done the day-to-day procedures of the fleet are likely to be influenced and the final results may not be typical of the fleet's normal operation. Regardless of how well the program is outlined, it still appears that at the start of a test every fleet, project engineer and manufacturer's representative involved should be visited by the test group coordinator. This permits a thorough discussion of all phases of the test and avoids mistakes and wrong impressions before they occur.

In any further field tests involving wear measurements, consideration should be given to the measurement of top cylinder bore sizes and ring gaps (or weights) of new engines before the test is started. Other measurements on new engines are not necessary. The cost of the test will be somewhat more, but the precision of the test will be improved. Older engines being rebuilt for test purposes will of course have necessary measurements taken.

Mass field test data properly collected is always of greatest value. If costs permit, more fleets and more vehicles should be used than were used in this test. In those fleets where mileages accumulated in one year are likely to be very low, it might be well to set up two duplicate groups of test vehicles. One group would be disassembled and measured at the end of one year; the other group would continue through to the end of the second year.

Fleet Owner's Contribution To Test Program

This paper would not be complete plete without giving credit to the contribution of the fleet owners toward

TABLE 4.

Fleet Number Vehicle Type	Test Location	No. of Vehicles on Test	Type of Service	Total Average Test Miles Per Vehicle	Sulfur Content, % Weight	Condition of Engine at Start of Test	Lowest Mean Minimum Temp. °F	Highest Mean Maximum Temp. °F	Average Miles/Day	Engine Starts/Day	Idle Period/Day	Oil Type and SAE Grade
Fleet 1 Vehicle A	Mid-Atlantic State	8	Heavy Duty	L 39860 H 39855	L .114 H .256	Rebuilt	16.7	86.3	114	1	1140	H.D. 30
Fleet 2 Vehicle B	Central Mid-West	8	Heavy Duty	L 87670 H 95536	L .091 H .281	New	19.3	88.3	240	7	5	Premium * 30
Fleet 3 Vehicle C	Large Mid-West City	8	Light Duty-Inter.	L 11139 H 10730	L .083 H .267	New	10.0	88.3	36	80	0	Premium 30 and 40
Fleet 4 Vehicle D	Large Mid-West City	8	Light Duty Inter.	L 5443 H 5067	L .086 H .267	New	10.0	88.3	15	15	7	Regular 10 and 20
Fleet 5 Vehicle E	Large Mid-West City	4	(Med. (Duty	L 18783 H 16168	L .056 H .269	New	10.0	88.3	52	13	58	Regular 30
Vehicle E	"	4	(Inter.	L 23270 H 20314	L .066 H .269	New	10.0	88.3	52	13	58	H.D. 30
Fleet 6 Vehicle D	Large West Coast City	6	Light) Duty)	L 3134 H 3450	L .140 H .290	New	38.8	67.7	10	11	5	Regular 20
Vehicle G	"	6	Inter.)	L 2912 H 2908	L .140 H .290	New	38.8	67.7	10	11	5	Regular 20
Fleet 7 Vehicle F	South West Coast	2	Med. Duty	L 14304 H 15276	L .132 H .264	New or Rebuilt	37.9	84.2	52	7	1	H.D. 30
Vehicle H	"	2	Light Duty-Inter.	L 6901 H 6829	L .132 H .264	"	"	"	18	19	2	H.D. 30
Vehicle HA	"	2	Med. Duty	L 14065 H 16336	L .132 H .264	"	"	"	38	8	2	H.D. 30
Vehicle I	"	2	Light Duty-Inter.	L 9011 H 4879	L .132 H .264	"	"	"	13	11	3	Premium 30
Vehicle J	"	2	Inter-Mittent	L 9965 H 8572	L .132 H .264	"	"	"	34	12	1	Premium 30

New British "Synthetic" Carbon

Discovery of the method of manufacture of Delanium, a special "synthetic" carbon product, has been announced by Duffryn Carbon Products, Ltd., of England. This remarkable product is carbonaceous material that is said to possess quasimetallic properties; it can be bored; cut to exacting tolerances; has very high mechanical strength, and can be fabricated to the most accurate specifications. It has a very fine, homogeneous pore structure, and is far more impermeable to fluids than any other known form of carbon; it has compressive strength varying from 20,000 psig for the "graphite" type, to 38,000 psig for the "carbon" type of product.

Its development hinged on the discovery that over a carefully controlled range of temperature a "jellified carbonaceous mass would decompose and simultaneously harden and shrink" *(Petroleum Times,* April 21, 1950, page 290). This shrinkage may be made great as to close completely the pores that otherwise would form a large part of the mass resulting from the decomposition. Among the uses already found for it include heat exchangers, as the cubical exchanger Paragrid tower packings and Delanium Carbon chemical tiles. The heat exchanger is built by boring a solid carbon block with alternate parallel lines of holes, the alternate lines being at right angles to each other, and staggered. Each 'bank' of holes is fed from headers of any desirable material fitted to opposite sides of the block, and any practicable number of passes may be provided for either exchanging material simply by the construction of the headers. Rate of heat transfer is high, due to the solid material between tubes or holes. It may be used for straight heating or cooling with steam or water or other transfer medium.

This exchanger occupies only one-sixth of the volume and one-eighth the floor space of the equivalent tube bundle type unit. A graphite block 9 by 9 by 9 in., smallest made regularly, has 10 sq ft of heating surface and a transfer coefficient of 300-500 Btu. For the same service a tube-bundle exchanger would be 6 ft long and contain seven $\frac{7}{8}$-in. ID tubes. The new material is made also into Paragrid tower packing units, in which Delanium strips are cut or sawed to permit construction of the units. The product is also useful for many types of linings and tiles, for chemical containers and vessels, turbine gland rings, etc.

making the test possible. It is unfortunate that coding of the report prevents giving their names. Besides those fleets actually used for the test, there were several others that indicated willingness to permit use of their equipment. Any test of this type is an inconvenience to the operator. In all cases the fleet owner was reimbursed for out-of-pocket expenses.

Without the help of these fleets, it is doubtful that a wide scale fleet test of the type just described could be run. The direct outlay in dollars for this test was slightly under 4 cents per mile. It is questionable that 30 cents per mile would have covered the costs of vehicles, drivers, fuel, oil and maintenance that would have been needed.

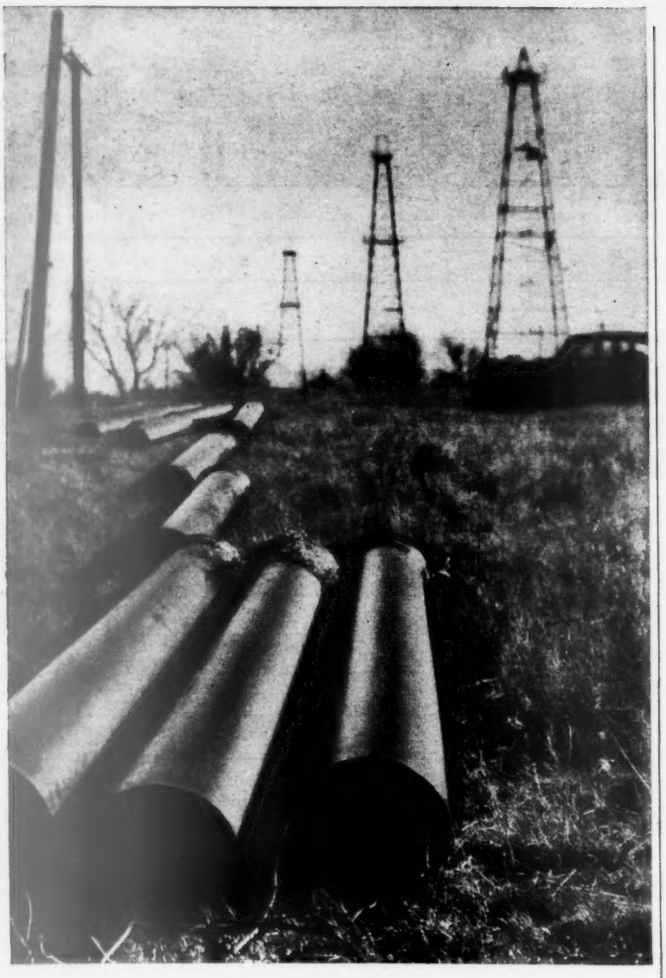
There is another point in regard to the fleet operator that bears examination. Work of this type builds respect and understanding. The fleet operator is brought to realize that his suppliers are on the alert to keep him out of trouble and to improve their products. All fleets have offered their equipment for further test programs.

The test data reported, show that the influence of up to 0.3 per cent sulfur in gasoline, as compared to gasolines of 0.1 per cent sulfur and lower, may vary from a pronounced effect on cylinder and ring wear under some operating conditions to no effect under continuous operation at normal engine temperature. This increased wear, to a considerable extent, does not check general field service experience, even in the areas where high sulfur gasolines have been widely used.

It is the opinion of the authors of this paper that there is ample material for study in the Coordinating Research Council report on sulfur in motor gasoline. The engine manufacturer and petroleum refiner may wish to do further work with their own products, using their own test facilities following the several avenues of investigation that are open to both. This is as it should be, since the problem is now theirs to establish competitive and economic boundaries. There may come a time when all concerned might like to conduct a further cooperative field test.

A full-scale cooperative field test involving several hundred people and a considerable expenditure of money and material has been completed. Each group, company or person who was in any way related to the test program fulfilled all of the obligations which they had agreed to undertake. In many cases the personal contribution of individuals was far above what one might normally expect.

There were differences of opinion, as one might expect from a group of technical people; however, general agreement was always possible. No two groups are more competitive within their respective industries than are the automobile and petroleum industries. Their ability to work together on this common problem is a tribute to their desire to serve their customers well! * * *



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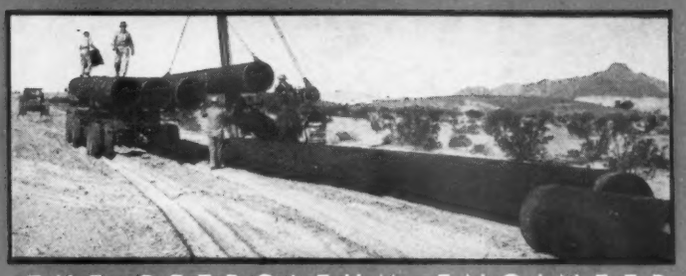

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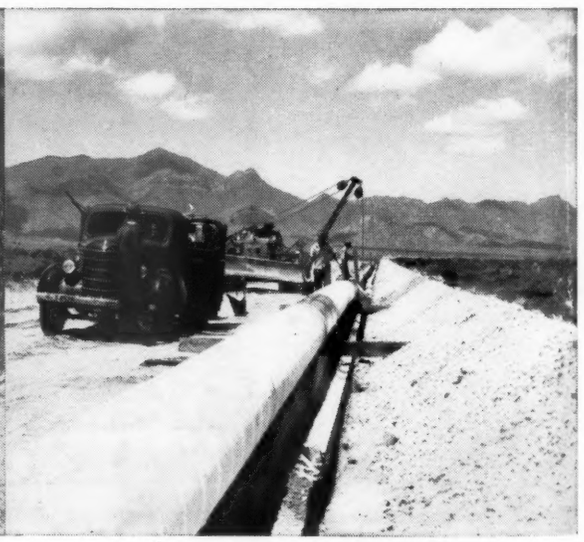

Above: Midwinter in Pennsylvania—Barrett A. A. Enamel will not crack at -20° F.
At right: Midsummer in the Arizona desert—Barrett A. A. Enamel will not flow, even at 160° F.

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Crude Oil Flow Characteristics Experienced in Large Diameter Lines

LOWELL E. ANDERSON†

WITH the advent of larger size lines for crude oil transportation, the question has arisen as to the flow characteristics encountered in these larger lines. The term large diameter is, of course, a comparative one but in this discussion will refer to lines with outside diameters of 16 in. and larger, as prior to the last few years there were few crude oil pipe line systems of any appreciable length composed of lines with a nominal diameter greater than 12 in. The increased laying of larger lines has paralleled the development of higher strength steel, permitting higher station operating pressures, together with improved methods of laying line. A further parallel has been the increased use of technical data for the design of new systems rather than rules of thumb formerly used. As the pumping rates through these larger lines are much greater, the need for an accurate knowledge of available throughput is gaining in importance so that the optimum size line will be used in the design of new facilities and the length of loops required to enlarge on present facilities can be determined accurately.

In hydraulic calculations involving crude oil, it has been found that the basic formula as introduced by Darcy in 1857 is the most applicable of the various flow formulas. This equation is a familiar one to all engineers and in its basic form is $h_f = \frac{f\,l\,v^2}{2gd}$. In this form the equation is solvable if the various quantities are expressed in foot-pound-second units giving the value of h_f in feet. This form is rather cumbersome, however, as units required in the above equation are not commonly used in pipe line terminology. This equation, after conversion to a more practical form, can be expressed as:

$$P = \frac{34.87\,fB^2s}{D^5} \quad . \quad . \quad . \quad . \quad (1)$$

where each of the terms has the following significance:

P = pressure drop, psi per mi.,
B = line throughout, bbl per hr.,
s = specific gravity of oil pumped,
D = internal diameter, in.
f = friction factor.

In this equation it is possible to measure physically all quantities with the exception of the dimensionless friction factor, which must be determined experimentally.

The customary means of expressing *f* is to plot its value against the corresponding value of Reynolds number, *R*, which is in existence in the line at that particular time. It is not necessary to dwell at length on this number as it also is familiar to all engineers. In its basic form it is expressed as:

$$R = \frac{dv\rho}{\mu} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Where:
d = diameter of pipe,
v = velocity of fluid,
ρ = density of fluid,
μ = absolute viscosity.

Any consistent set of units can be used such that the value of R will be dimensionless. This equation can also be expressed in a form more readily used and remembered by engineers. This converted form is:

$$R = \frac{2214 \times B}{D \times v} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where B and D have the same significance as set out above and v is the kinematic viscosity of the oil moving through the line, expressed in centistokes. To further clarify the formula, the relationship between centistokes and Saybolt Universal Seconds, a more common way of expressing viscosity, can be set forth by a simple equation:

$$\text{Centistokes} = 0.22t - \frac{180}{t} \quad . \quad . \quad (4)$$

where *t* represents Saybolt Universal Seconds.

A basic relationship between *f* and *R* has been established for streamline flow and verified by many experimenters so it will be valid for the lines here investigated. This relationship can be expressed by the equation $f = 64/R$, which when substituted in equation (1) gives:

$$P = \frac{1.008\,B}{D^4\mu} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where μ is the absolute viscosity in centipoises.

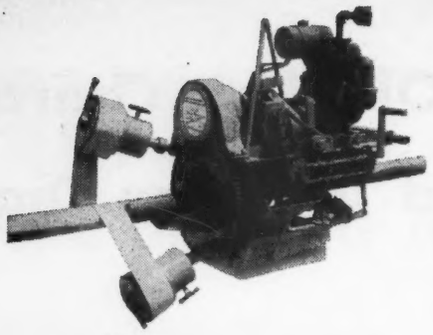
Experimental work done by Stanton and Pannell on fluid flow through pipes embraced a wide set of flow conditions and has been recognized as one of the most authoritative pieces of work on this subject. Their experiments were carried out using air and water moving at different rates through smooth drawn brass pipe varying in diameter from 0.361 cm to 2.855 cm. The curve propounded by these authors is shown in Fig. 1, plotted on double logarithmic paper. This shows the two distinct regions of flow, streamline and turbulent.

It is the purpose here to describe tests run recently for the evaluation of the friction factor *f* in large diameter lines in the turbulent flow region and to express the results obtained from these tests. The intent in carrying out this investigation was to procure data that would be of direct use in hydraulic calculations on commercial pipe lines rather than data that would be of academic interest only. Numerous papers such as that of Stanton and Pannell have been written on the value of *f* as determined by laboratory experimentation, using various fluids such as water and air in small diameter lines. Our purpose was to determine which data, if any, obtained from these laboratory experiments would be confirmed by results obtained from large diameter lines moving crude oil. Various authors concur with the reasoning that their results obtained from smaller lines may not hold true for larger lines.

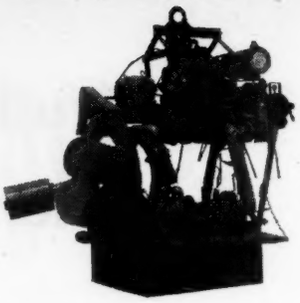
To get information such as was desired, sections of line in our system were utilized as test sections, thus providing the best large-scale laboratory possible. The friction factor was determined in each of a series of test runs on each section of line. This was done by using equation (1), measuring the four quantities, P, s, B, and D and solving for the unknown friction factor. To measure the pressure drop, P, recording pressure gauges were normally used. One was installed at

*Presented before The American Society of Mechanical Engineers, Oklahoma City, Oklahoma, October 2-5, 1949.
†Service Pipe Line Company.

PIPELINE

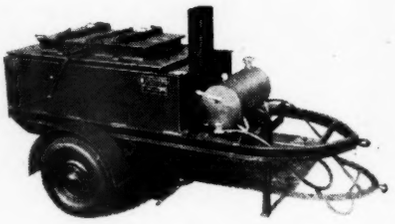


The 2" - 4" Crose line-traveling coating and wrapping machine illustrated is light weight and compactly designed. These features are extremely essential for proper coating of small diameter pipe. Equipped with the patented Crose coating spray ring.

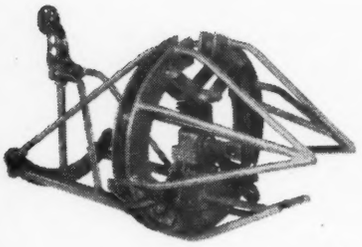


The 22" - 26" Crose line-traveling coating and wrapping machine. These machines are available for coating and wrapping pipe sizes from 2" to 34" in diameter. The positive application of coating through our patented coating spray ring gives these advantages: 1. Coats bends as well as straight pipe. 2. Applies coating to pipe that has been "egged" or bent out of shape. 3. Reduces patches on bends to absolute minimum.

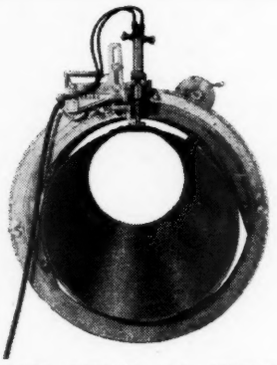
CROSE COATING STRAINERS fit all makes of pipeline coating kettles—has easily removable wire mesh filter element.



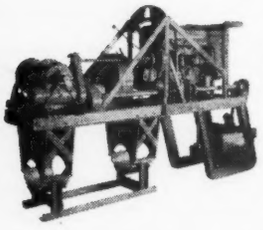
225 GALLON PATCH KETTLE is equipped with manual agitator. Available as illustrated or on steel wheels. These units are now being used for patch work and maintenance on pipelines. This unit also available in 165 gallon capacity.



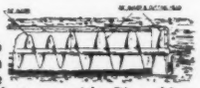
CROSE INTERNAL LINEUP CLAMPS are available in manual, electric and hydraulic models for pipe sizes ranging from 12" to 36". Crose Internal Lineup Clamps have been proven in world-wide field operations.



CROSE PIPE CUTTING AND BEVELING MACHINES—Ideal for fast, true cutting and beveling of pipe. Available in six sizes for 4" to 36" pipe. Machines for 16" pipe and above have "Out-of-Round" Attachment as standard equipment. Made of strong aluminum alloy.

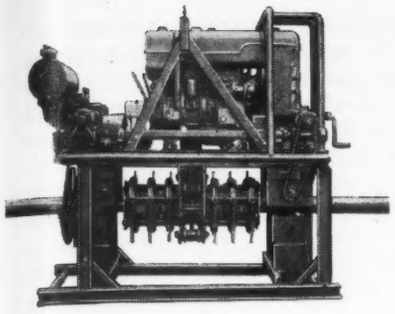


CROSE AUGER TYPE ROAD BORING MACHINE

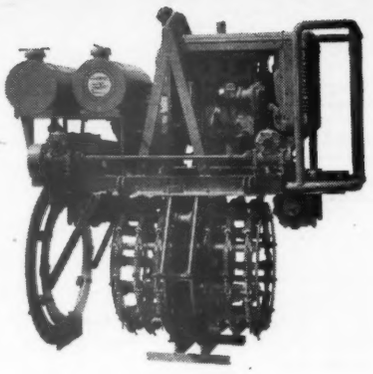


Installs pipe casing up to and including 34" in diameter. This machine has proven highly satisfactory with Pipe Line Contractors for the fastest method of installing pipe casing where rock is not encountered. Machines for installing casing larger than 34" in diameter are also available.

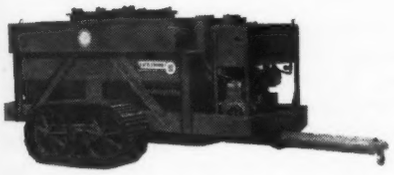
CROSE PIPE CRADLES handle pipe sizes from 4" to 34" in diameter. Cradle illustrated can be adjusted to cradle pipe from 16" to 26" in diameter.



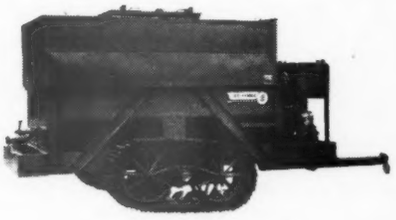
MODEL "M" PIPE CLEANING AND PRIMING MACHINE can be set up to clean and prime pipe from 2" to 14" in diameter. May be used as a line-traveling machine or on a stationary base for yard work.



MODEL "K" PIPE CLEANING AND PRIMING MACHINE can be set up to clean and prime pipe from 16" to 26" in diameter. May be used line-traveling or on stationary base. This machine is also available for larger pipe sizes.

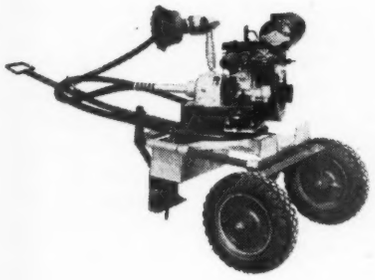


23 BARREL CAPACITY

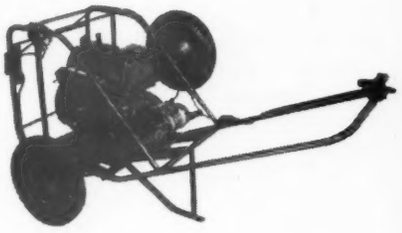


30 BARREL CAPACITY

CROSE-LITTLEFORD PIPE COATING KETTLES are equipped with hydraulically controlled agitator, low pressure burner, dial-type thermometer and a Wisconsin air-cooled gasoline engine with electric starter. If the agitator becomes fouled, the hydraulic fluid by-passes until the agitator is freed. The low pressure burner uses any type of low-grade fuel oil and distributes heat equally over all parts of the bottom. This burner is designed to avoid hot spots thereby eliminating the necessity of replacing bottoms. These completely insulated kettles may be purchased on Athey tracks or on skids for stationary coating yards. Over 150 of these kettles are in service in the United States and Canada.

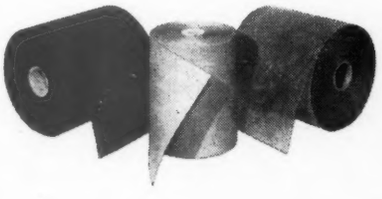


CROSE PORTABLE BUFFING UNIT is used to operate sanding discs or wire wheels for cleaning stringer beads or pipe bevels.



1500 WATT SELF PROPELLED GENERATOR is a utility unit for operating wire brushes, buffers and cleaning bevels. May be used as utility light plant.

CROSE ENDLESS PIPE BELT SLINGS are stronger and lighter in weight than conventional type belt slings. No bolts or steel strapping necessary. These pipe belt slings are available for pipe sizes from 12" to 36".



PIPE WRAPPING MATERIALS — VITRON Glass Fiber Underground Pipe Wrap has been proven on thousands of miles of pipeline. VITRON Glass Fiber Underground Pipe Wrap, Asbestos Felt and Kraft Paper are all available for immediate shipment from warehouse stocks at Tulsa, Okla. or Houston, Tex.

CROSE

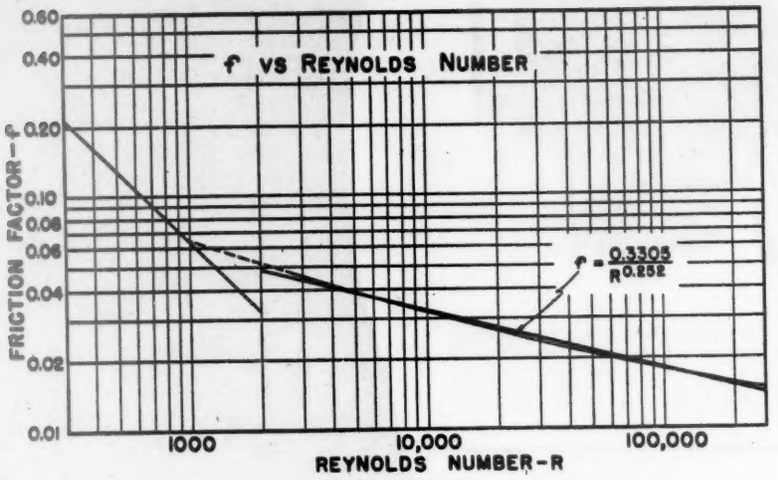


FIG. 1. Crude oil flow characteristics experienced in large diameter lines.

each end of the test section of line and calibrated in place by means of a deadweight tester. For the measurement of specific gravity, periodic samples were taken from the line and the gravity determined by means of a hydrometer. The gravities of the crude in the lines varied from 32 deg API to 44 deg API. An accurate measurement of the volume of oil pumped through the line is necessary in order to obtain the pumping rate, B. The most desirable method is to pump decrease out of one tank so that the actual volume can be determined from hourly tank gauges. If this procedure is not possible, meter readings may be used if such an installation is available, provided the meter has been recently calibrated and its accuracy assured. The internal diameter used is the nominal internal diameter of the line with no allowance being made for manufacturing tolerances. Just prior to the running of a test, a pig-type scraper was run through the line to remove any wall deposits that would have the effect of reducing the internal diameter, which would in turn give a higher value for the calculated friction factor.

To compute the value of R to correlate with the value of f, it is necessary to determine the viscosity of the oil being pumped, this value then being used in equation (3). The ordinary method of measuring viscosity is by use of a commercial viscosimeter, such as the Saybolt Universal type of instrument, which measures the time of efflux of a prescribed amount of liquid through a calibrated orifice. However, these tests run at atmospheric pressure do not give the true viscosity of the oil while moving through the line under pressure. It was known that viscosity increased with pressure, but a perusal of available literature on the subject yielded nothing that was specific enough to be applicable for our use. The effect of pressure on viscosity is gaining in importance due to the trend toward higher operating pressures. To obtain information on conditions existent in our system, tests were run to determine how viscosity varied with pressures normally encountered in pipe line operation. Fig. 2 shows the results obtained from two crudes analyzed in this manner by means of a falling ball type of viscosimeter. The East Central Texas crude is one of the lightest common stream crudes handled in our system and the Wyoming crude is the heaviest common stream crude moved through our lines. An examination of Fig. 2 shows that the relationship between pressure and viscosity is apparently a straight line function. At higher temperatures, the per cent increase in absolute viscosity per 1000 psi is about the same for the two crudes, but at lower temperatures the effect of pressure is much greater on the lighter crude than on the heavier Wyoming crude. Also, for either of the particular crudes, the increase in viscosity due to increased pressure is a greater percentage at lower temperatures. From the trend indicated on the curves, it appears that if the temperature is increased sufficiently, there may be a point at which pressure will have no effect on viscosity; however, this supposition would have to be proved or disproved by actual tests.

It is obvious now that using viscosity determined at atmospheric pressure by means of commercial viscosimeters will give erroneous values. With this added information, our problem now is to seek to utilize this information in a simple manner. As realized from past experimentation and evidenced by this investigation, the science of turbulent flow is not an exact one such as is experienced under streamline flow conditions. Instead, the basic equation includes the empirical term f, which is dependent on many variables and will itself vary over a certain range for the same type of pipe. Because of the inability of quantitatively measuring f, it is proposed to make its value dependent on one more variable —the change in viscosity due to pressure. As the operating pressures of most trunk line stations do not vary widely, this effect will be a fairly consistent one so it is proposed not to use a viscosity correction factor, but instead to plot the values of f determined against the apparent value of R. The apparent value of R will be the value of this term based on the viscosity determined at atmospheric pressure.

Although the effect of viscosity change in turbulent flow is an indirect one, by reference to equation (5) it is seen that in streamline flow the pressure drop is directly proportional to the absolute viscosity, so using the correct viscosity is of major importance. Normally, crude oil flow is in the turbulent region, but there are cases where streamline flow is encountered such as in winter months in lines moving the heavy Wyoming oil shown in Fig. 2. As pressure vs. viscosity gives a straight line, the viscosity determined at atmospheric pressure can be corrected by using a correction factor based on the average line pressure. It is difficult to determine the average line pressure exactly due to ground profiles being very irregular but for most cases, the average line pressure in a section of line can be assumed to be one-half the station discharge pressure. No investigation has been made into streamline flow in actual operation to determine how closely theoretical conditions will be approximated.

As a counteraction to the effect of pressure on viscosity, some crudes are of a thixotropic nature, i.e., their apparent viscosity decreases as the shear rate increases. The shear rate in any one size line would increase as the pumping rate increases. This characteristic is noticed especially in high paraffin base crudes such as those produced in southwestern Wyoming. On one pipe line system operating in this area, normal operating pressures as high as 2000 psi are encountered, thus resulting in a larger throughput and a corresponding high shear rate. In expressing the viscosities of these crudes, viscosities determined by an efflux type viscosimeter will give a false indication of the viscosity of the oil moving through the line. Instead, a viscosity-temperature curve should be used

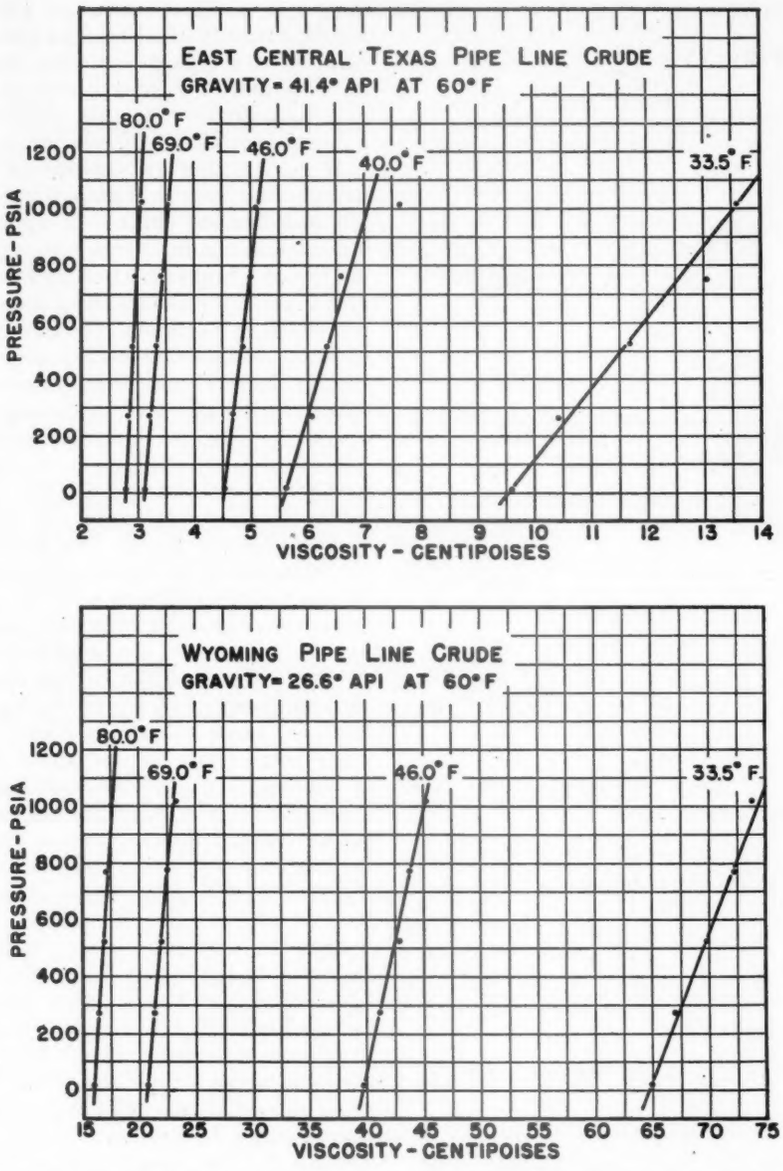


FIG. 2. Crude oil flow characteristics experienced in large diameter lines.

showing apparent viscosities determined from a study of actual operations. The Brookfield type of viscosimeter, which measures the resistance of liquid offers to a rotating cylinder, simulates actual shearing conditions so should come close to presenting the true viscosity of the oil at atmospheric pressure. Most crude oils are of the Newtonian type, however, as their apparent viscosity at any certain temperature is constant regardless of shear rate. For this type of crude, a normal temperature-viscosity curve as determined by means of an efflux viscosimeter can be used for determining uncorrected line viscosities.

The section of the Stanton and Pannell f vs. R curve between Reynolds number of 30,000 and 240,000 has been reproduced in Fig. 3 and the writer's experimentally determined values for f have been plotted against the apparent R. As shown on the graph, these points were calculated from tests run on lines of 16 in., 20 in., and 30 in. diam. An examination of the graph shows that the writer's points determined from the 16-in. lines approximate the Stanton and Pannell curve very closely. The average of the points from the 20-in. line fall slightly above the curve and the three points representing the 30-in. line are still higher above the curve.

The values of f from the 16-in. and 20-in. diam lines were determined in all cases from sections of trunk line many miles in length, which in most cases included very few valves and no junctions, making the values representative of straight pipe. Much of the 16-in. line has been in West Texas sour crude service for a period of more than five years. The 20-in. sections tested have been used for both sour and sweet crude and have been in service from one to two years.

The values shown for the 30-in. diam line were obtained from a section of tank line approximately ½ mile in length. This line was just recently laid and is used for sour West Texas crude. Because of its short length and corresponding small pressure drop, it was necessary to measure the pressure differential by means of a manometer installed at each end of the line. Due to insufficient data on the 30-in. line, no definite conclusions can be reached but it is felt that in trunk line service, the friction factor for this size line will be somewhat lower than shown here. The 30-in. tank line tested was ¼-in. wall pipe and was laid above ground so it was probably not perfectly round as the pressure in the line did not exceed 15 psi. In addition, the test section included an expansion joint that would have the effect of increasing the pressure drop slightly, resulting in a higher apparent friction factor.

Moody[1] has drawn a family of friction factor curves based on different relative roughnesses. The lowest curve in this family is for smooth pipe and approximates the Stanton and Pannell curve. The relative roughness, ξ/D, as given by Moody for commercial steel pipe in the range of sizes here discussed is low enough that it can be considered as smooth pipe in the range of Reynolds numbers normally encountered.

Drew, Koo, and McAdams[2] made a survey of work done on determination of the friction factor to ascertain if Lee's equation, which was based on the data of Stanton and Pannell, gave values for f that were representative of smooth pipe. Their investigation showed that the majority of experimental work, up to a Reynolds number of 500,000, validated Lee's equation. These authors also studied work done on commercial iron and steel pipe and as a result of this study presented a curve for f somewhat higher than that for smooth pipes. The work they reviewed was all carried out on small diameter pipe and they state that smaller size pipes generally give higher values for f.

Other experimental work has been done by Heltzel[3] at lower Reynolds numbers on lines 6 in. to 12 in. in diam in crude oil service and the validity of the Stanton and Pannell curve for this use has been verified by him. It is be-

1. "Friction Factors for Pipe Flow," by Lewis F. Moody, *ASME Transactions*, Vol. 66, 1944, pp 671-684.
2. "The Friction Factor for Clean Round Pipe," by T. B. Drew, E. C. Koo, and W. H. McAdams, *AIChE Transactions*, Vol. 28, 1932, pp 56-72.
3. "Fluid Flow and Friction in Pipe Lines," by William G. Heltzel, *The Oil and Gas Journal*, Vol. 29, No. 3, June 5, 1930.

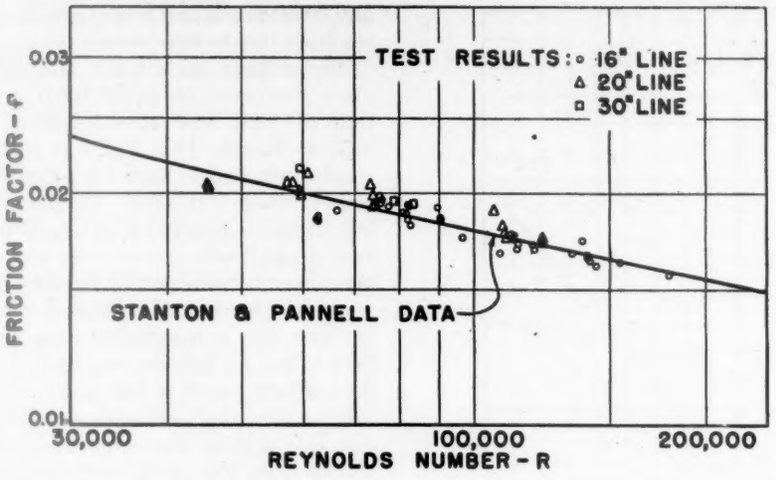


FIG. 3. Crude oil flow characteristics experienced in large diameter lines.

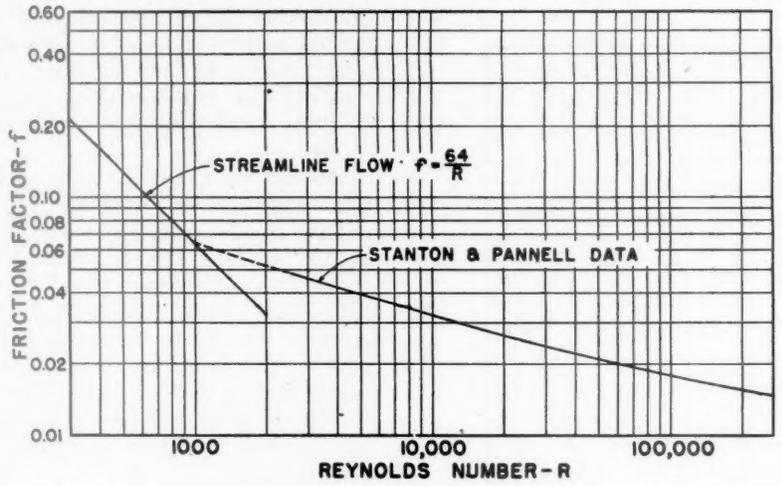


FIG. 4. Crude oil flow characteristics experienced in large diameter lines.

lieved the test data accumulated here is sufficient confirmation of this curve to warrant using it for large diameter lines. Although these tests did not cover the entire range of R encountered in these lines, the range covered includes the majority of normal flow conditions. Because the Stanton and Pannell curve has thus been substantiated for a wide range of pipe sizes, an expedient equation based on this curve will be developed for determining directly trunk line capacity. The use of equation (1) for determining line capacity is rather laborious as it is necessary to use a cut and try method for determining the value of f to use in the equation. The range of R normally encountered in our crude oil lines does not exceed 200,000 with the majority of flow conditions giving a value of R less than 100,000. Our problem now is to develop a relationship between f and R that will give fairly consistent results over the entire range of turbulent flow conditions found in our work. To do this, a straight line is drawn between points on the Stanton and Pannell curve corresponding to R of 6000 and 130,000, as shown in Fig. 4. It can be seen that this straight line does not vary widely from the curve at any point. By simple mathematics, the equation of this line is calculated to be:

$$f = \frac{0.3305}{R^{0.252}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

but:

$$R = \frac{2214 \times B}{D \times v},$$

which substituted in equation (6) gives:

$$f = \frac{0.0474\, D^{0.252}\, v^{0.252}}{B^{0.252}} \quad . \quad (7)$$

This in turn is substituted in equation (1) and the resultant form is:

$$P = 1.653\, \frac{B^{1.748}}{D^{4.748}}\, v^{0.252}\, s \quad . \quad . \quad (8)$$

Solving this equation for B gives the following:

$$B = \frac{0.750\, P^{0.572}}{v^{0.144}} \quad \frac{D^{2.716}}{s^{0.572}} \quad . \quad (9)$$

Although this is unwieldy to use, it does give a direct means of solving for the capacity of a line. The greatest value of this type of equation lies in its adaptability of logarithmic charts or a logarithmic slide rule, providing a convenient means of solution.

It is felt that the choice of the straight line for v vs. R above the Stanton and Pannell curve will approximate actual conditions very closely as the use of a higher friction factor will give a greater pressure drop than encountered in a straight pipe line. This higher pressure will compensate for certain factors not now considered that have the effect of increasing the operating pressure. Under our present method of calculating, no provision is made for the additional pressure loss through valves, fittings at junctions, and station manifolds. The basis of our calculations is the actual distance of line between stations with the correction for elevation head being taken as the difference in elevation between the station floors. Though most of our stations operate with a tank floating on the line, there are times when they pump their entire stream into a tank at the next station. This would have the effect of increasing the discharge pressure at the pumping station due to the additional pressure drop through the tank line. No correction is made for these operating conditions although the tank lines are ½ mile in length at some stations. An additional factor that will be corrected for by using a higher line for f is the decrease in effective internal diameter between the running of scrapers. As the lines grow older, the value of f experienced may increase due to internal corrosion in some lines, although past performance has shown this factor to be a negligible one in trunk lines where velocity is sufficient to prevent the settling out of water, the primary cause of internal corrosion.

Considering the effect on capacity, the maximum difference is 2.7 per cent between using the straight line for f and the Stanton and Pannell curve for f.

Although it is realized that the data presented here are not all-inclusive, it is felt that it is a realistic addition to the field of pipe line hydraulics. The accumulation of data such as included here is time-consuming as well as costly, but it is hoped that further study can be made of flow conditions in commercial pipe line systems.

The writer wishes to acknowledge the help of members of the engineering department of the Stanolind Pipe Line Company and particularly the aid of L. E. Tomlinson and W. E. Roads who assisted in some of the test work and offered helpful suggestions in compiling the data. * * *

Pipeline
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P 615.92

History and Development of Products Pipe Lines*

JOHN W. de GROOT†

In considering the history and development of products pipe lines, it seems desirable to choose a definite year as a starting point from which to trace the growth to date of refined-products pipe lines. For the purposes of this paper, the year 1930 is taken as the initial year of commercial-products pipe line operations in the United States. Developments in the pipe line transportation of natural gasoline and kerosine go back considerably further than 1930; and, as they are factors contributing to the start of a new industry, it would be well to review them here in this light.

Early Refined-Products Lines

Probably the earliest movement of refined products of any significance started in 1901, when the United States Pipe Line Company started using one of a pair of parallel 4-in. and 5-in. lines for the batching of three grades of kerosine. The lines had been laid in 1892 between Titusville and Wilkes Barre, Pennsylvania, and the success of the kerosine movement prompted an extension of the system in 1902 to Marcus Hook, Pennsylvania. The system remained in intermittent kerosine service until 1926.[1] In 1902 The Standard Oil Company (Ohio) placed in operation a 4-in. line from its refinery to the East Ohio gas plant, a distance of 7 miles through a congested section of Cleveland. The line was used to carry a 32-deg-API-gravity oil, which apparently was used for gas enrichment. The line was abandoned in 1914; and, upon having been opened recently, was found to be in excellent condition, and with a few pounds of pressure on it. The only other refined-product movement of record prior to 1930 started in 1929, when the Standard Oil Company of California converted a 20-mile 10-year-old crude-oil line to motor-gasoline service; and that line, with a subsequent rebuilding, remains in service today.

*Presented before the American Petroleum Institute, Chicago, Illinois, November 8, 1949.

†Tuscarora Oil Co., Ltd., Harrisburg, Pennsylvania.

Natural Gasoline Lines

Natural gasoline transportation by pipe line is believed to have begun in 1912 in southern California, with the building of a 2-mile 2-in line, followed in 1913 and 1914 with other 2-in. lines 16 and 30 miles long, respectively.[2] The year 1915 saw the first natural gasoline line in Pennsylvania, when the Peoples Natural Gas Company of Pittsburgh completed a 2-in. line from an absorption plant 23 miles to railroad.[2] The Midwest Refining Company in 1918 placed in service what is believed to be the first all-welded liquid-petroleum pipe line from its Salt Creek gasoline plant to Casper, Wyoming, 40 miles of 3-in. pipe, bringing gasoline pipe line transportation to the Rocky Mountain area.[3]

By 1930 natural gasoline pipe lines had invaded the "larger and longer" class with three lines, of 4-in. and 6-in. diam, totaling 260 miles in length in operation in southern California.[4] Of these three lines, it is interesting to note that Shell Oil Company's 97½-mile 4-in. line from the Ventura Avenue field to Wilmington, California, had an intermediate pumping station that employed a motor-driven centrifugal pump, and which was completely automatic in its operation. This automatic station had two right-hand float controls switching the pump off and on at capacity limits of the pressure

TABLE 1. Refined-Products Pipe Line—Vital Statistics, 1930-1949

	1930	1935	1940	1945	1948	1949
Total mileage of pipe in refined products pipe line service	1,289	4,471	8,040	12,857	18,399	20,109
Total right-of-way mileage in refined products pipe line service	1,125	4,015	6,890	11,439	16,601	18,053
Total refined products, barrels terminated by pipe line (thousands)	5,491	45,746	105,835	230,019	333,562	365,603
Total refined products, barrel-miles pumped (millions)	2,245	16,749	29,221	76,061	104,494	109,973

TABLE 2.

Refined Products Pipe Line Right-of-Way—Mileage by States (1930-1949)

	1930	1935	1940	1945	1948	1949
Alabama	0	0	0	281	281	281
Arizona	0	0	0	0	0	0
Arkansas	0	0	0	168	202	202
California	20	20	20	20	20	49
Colorado	0	0	0	0	214	214
Connecticut	0	0	26	26	26	26
Delaware	0	0	0	0	0	0
Florida	0	0	0	78	78	78
Georgia	0	0	0	794	811	811
Idaho	0	0	0	0	0	230
Illinois	0	137	814	849	1,114	1,359
Indiana	0	0	201	612	612	710
Iowa	0	507	625	950	1,046	1,060
Kansas	325	731	1,049	1,253	1,560	1,540
Kentucky	0	0	6	6	6	6
Louisiana	0	0	0	345	441	441
Maine	0	0	0	0	0	127
Massachusetts	0	79	86	180	204	204
Maryland	0	0	0	74	74	74
Minnesota	0	124	124	124	848	848
Michigan	0	68	71	71	126	127
Mississippi	0	0	0	165	165	165
Missouri	247	356	467	479	479	887
Montana	0	0	0	0	0	0
Nebraska	0	7	199	433	609	609
Nevada	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0
New Jersey	47	47	103	104	104	104
New Mexico	0	0	0	0	0	0
New York	0	88	412	521	521	528
North Carolina	0	0	0	106	106	106
North Dakota	0	0	0	0	70	70
Ohio	0	113	478	584	1,020	1,070
Oklahoma	78	338	405	376	864	785
Oregon	0	0	0	0	0	0
Pennsylvania	323	1,292	1,462	1,850	2,175	2,355
Rhode Island	0	21	21	21	21	21
South Carolina	0	0	0	100	100	100
South Dakota	0	0	10	81	167	167
Tennessee	0	0	0	106	106	106
Texas	85	87	311	675	2,235	2,307
Utah	0	0	0	0	0	90
Vermont	0	0	0	0	0	0
Virginia	0	0	0	0	0	0
Washington	0	0	0	0	0	0
West Virginia	0	0	0	7	7	7
Wisconsin	0	0	0	0	0	0
Wyoming	0	0	0	0	189	189
	1,125	4,015	6,890	11,439	16,601	18,053

tank, and the left-hand float manually regulating a throttle valve to maintain a normal tank level during operation of the line.[2]

Gasoline Lines

These developments in successful natural-gasoline pipe line operation led a group of Mid-Continent refiners actively to consider the construction of a motor-gasoline line from Oklahoma to a Mississippi River point in the late '20's. They finally abandoned their plans, however, apparently believing that product identity could not be successfully maintained. With the adoption by many states of a 1927 government master specification for liquid fuels, this objection—more mental than actual—was largely overcome, and the way paved for the start of the new era in 1930.[2]

On February 1, 1930, the Tuscarora Oil Company, Ltd., began pumping its first tender of motor gasolines out of Bayway, New Jersey, toward its destination in Midland, Pennsylvania, 370 pipe line miles away. The event climaxed a preparation period of almost a year, during which time the line had been converted from its status as a 20-year-old crude-oil pipe line west-to-east to a gasoline line east-to-west.

At about the same time the Phillips Pipe Line Company began work on a 735-mile gasoline line from its refinery at Borger (Texas Panhandle) to Kansas City and St. Louis—completing the line and placing it in service the same year.

Also early in 1930 plans were announced of the joint venture of 6 leading Mid-Continent refiners in the formation of the Great Lakes Pipe Line Company to build a 1240-mile gasoline pipe line from 8 northern Oklahoma and Kansas refineries to heavy consuming areas around Kansas City, Omaha, Des Moines, Minneapolis-St. Paul, and Chicago. Construction began the same year.

A New Era

With this great burst of activity marking the year 1930 as the start of the refined products pipe line era, it is not surprising to note that late in 1930 the midwestern railroads considered a proposal to lower rates to meet the impending competition in their area.[5]

In connection with rates, it may be noted that the first Tuscarora gasoline tariff showed rates 25 to 60 per cent below rail rates for equivalent distances—the 60 per cent on the longer hauls—and that only a few months in operation at these rates was sufficient to establish a 10 per cent pipe line tariff reduction.

The year 1931 was another year of great activity in the new race to build gasoline pipe lines from refining to consumption areas. Pennsylvania really began to become products pipe line conscious. In 1931 the Susquehanna Pipe Line Company completed its system from Marcus Hook across Pennsylvania to Akron and Cleveland, Ohio, and north through the coal regions to Syracuse, New York. The formation of the Keystone Pipe Line Company for the purpose of building gasoline lines in Pennsylvania was announced that same year, and work was begun promptly on 225 miles of line to serve Reading, Harrisburg, Scranton-Wilkes Barre with refined products from Philadelphia. National Transit Company in 1931 built and placed in operation a 6-mile 2-in. gasoline line from a cracking plant at McClintock to Reno, Pennsylvania.

Also in 1931 the Standard Oil Company of New York built a gasoline line out of its Providence, Rhode Island, refinery to serve Worcester and Springfield, Massachusetts—the first products pipe line for New England. The Great Lakes System, started in 1930, was completed and placed in service in 1931.

So the beginnings of the product pipe line industry were well established during the first two years of the '30's, and have led us on through the intervening years in a pattern of growth that best can be seen by reference to the charts, tabulations, and maps in this paper.

FIG. 1-A

FIG. 1-B

Period of Rapid Growth

Fig. 1 [(A) through (F)] shows the location of refined products pipe lines by 5-year intervals 1930 to 1945, 1948, and 1949. The areas of future product line concentration were defined by the two major lines shown on the 1930 map. By 1940, these two areas were considerably covered with products lines. During the war years, links reached out that almost joined these two areas; and a third section of the country, the southeastern states, came into products line prominence. It might be well to point out here that no government-sponsored wartime products lines that have since been removed from products service are considered in any phases of this study. By 1948 the evidences of a northern expansion of the Mid-Continent outlet lines can be seen, together with a link between the Gulf Coast and the central states. 1949 brings further products line concentration to the heavily lined areas; establishes a through link from the Gulf Coast to eastern refining centers; and finds a products line pushing out towards the Pacific Northwest and a new pipe line frontier.

In Table 1 are tabulated what might be called the "vital statistics" of the products pipe line industry. Although the amazing growth of the industry prewar is spectacular in itself, perhaps more so is the postwar expansion, which shows in the 4-year period 1945-1949 a better than 55 per cent increase in both mileage of products lines and barrels delivered to terminals. The war years themselves were a period of tremendous products line growth, with 60 per cent more mileage in operation in 1945 than in 1940, and with the barrels delivered more than doubling in this 5-year period. The barrels delivered in each case are barrels delivered to terminal, and thus do not include barrels handled by lines serving as feeders into other lines. Total barrels handled by products lines postwar are about 8 per cent greater than barrels terminated.

Gasoline for Vacation

The average American on vacation this year will travel a greater distance and spend more money for gasoline, oil and food than ever before, according to a magazine survey. Mr. Tourist is expected to spend an average of $279 and travel 1630 miles. That is $66 and 381 miles above the figures for 1949.

FIG. 1-C

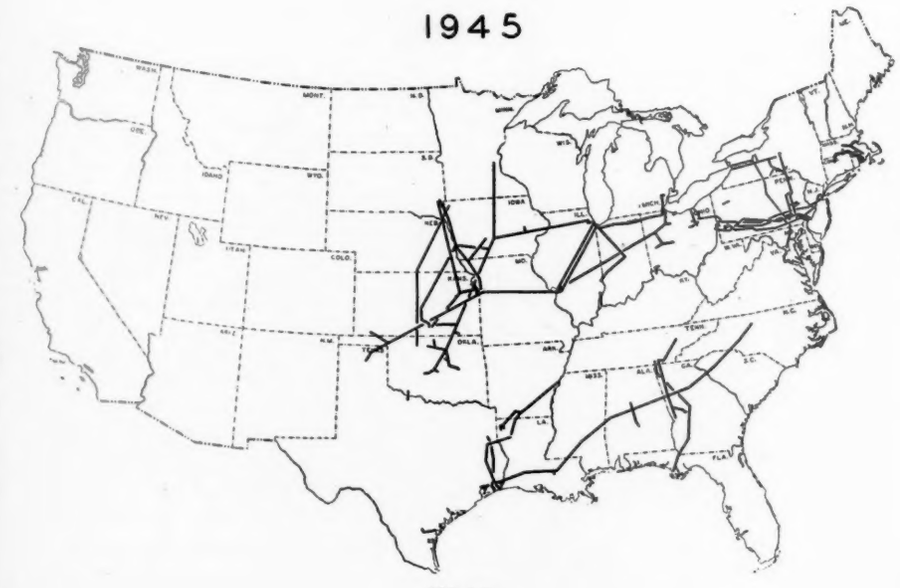

FIG. 1-D

The ratio between miles of pipe and miles of right-of-way is indicative of how much looped line is in operation; and, surprisingly, this has changed little percentagewise during the entire existence of products lines. It varies in the vicinity of 112 per cent, but shows no tendency toward significant change.

A similar situation prevails with the "average haul," the ratio of barrel-miles to barrels. It has varied considerably from interval to interval, but indicates a consistent reduction in postwar years.

Table 2 tabulates right-of-way mileage by states, and gives in numerical form what has already been seen on the maps in Fig. 1. It would probably be well to point out here that in this entire study lines purely for the transportation of natural gasoline have been excluded. LPG (liquefied petroleum gas) lines have been included because they carry a product ready for consumption, even though its origin may in some cases be the producing fields and its destination a refinery.

A tabulation of pipe by sizes is shown in Table 3. No stability in trends is shown for the early years. From 1945 on, however, decreases in the percentage of 4-in. and 6-in. pipe are offset by corresponding increases in the prevalence of 8-in., 10-in., and 12-in. pipe.

In Table 4 are tabulated some of the less important but more interesting statistics for the products pipe line industry. The number of pumping stations increases, but not in proportion to the right-of-way mileage—and thus a definite, although small, increase in the average station spacing is seen

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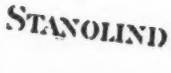

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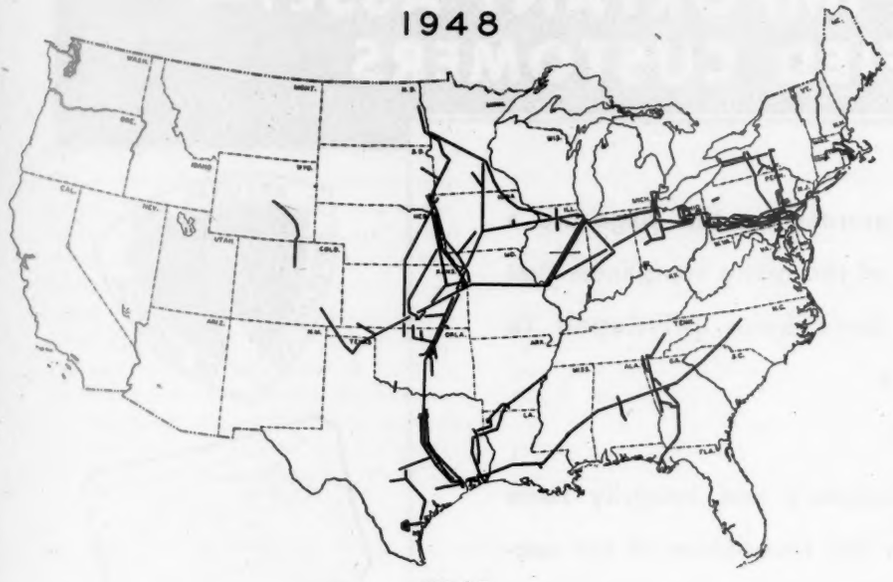

FIG. 1-E

FIG. 1-F

TABLE 3. Refined Products Pipe Line Mileage—by Pipe Size (1930-1949)

	1930		1935		1940		1945		1948		1949	
	Miles	Per cent	Miles	Per cent	Miles	Per cent	Miles	Per cent	Miles	Per cent	Miles	Per cent
2-in.	.....	....	11	0.2	15	0.2	35	0.3	40	0.2	40	0.2
3-in.	.....	....	73	1.6	78	1.0	85	0.7	136	0.7	136	0.7
4-in.	1	....	233	5.2	514	6.4	675	5.2	789	4.3	717	3.5
5-in.	.....	.....	.....	.....	83	1.0	83	0.6	83	0.5	83	0.4
6-in.	197	15.3	2,136	47.8	3,457	43.0	5,204	40.5	6,039	32.8	6,266	31.2
8-in.	998	77.5	1,926	43.1	3,761	46.8	5,530	43.0	8,944	48.6	10,217	50.8
10-in.	.....	.....	1	....	4	0.1	696	5.4	1,582	8.6	1,602	8.0
12-in.	93	7.2	91	2.1	128	1.5	549	4.3	786	4.3	1,048	5.2
Total	1,289	100.0	4,471	100.0	8,040	100.0	12,857	100.0	18,399	100.0	20,109	100.0

TABLE 4. Refined Products Pipe Lines—Miscellaneous Statistics (1930-1949)

	1930	1935	1940	1945	1948	1949
Number of pump stations	18	99	150	236	311	325
Average station spacing	62.5	40.6	46.0	48.5	53.4	55.5
Number of delivery terminals	11	65	133	204	261	280
Average terminal spacing	102	61.8	51.8	56.0	63.5	64.5
Total installed horsepower	8,875	46,300	82,600	165,200	251,300	267,600
Installed horsepower per million barrel-miles pumped	3.95	2.77	2.83	2.17	2.40	2.43
Miles of pipe coated	23	310	1,617	4,817	10,103	10,993
Average coated, per cent	1.8	6.9	20.1	37.5	54.9	54.7

from 1935 on. This increase is consistent with the recent trend toward the larger pipe sizes and higher working pressures.

The average spacing of delivery terminals decreased in the prewar decade, but since that time has been increasing. A possible reason for this behavior is that during 1930-40 construction was principally concentrated in competitive pipe line areas, with a resulting closeness of delivery points. The post-1940 tendency of products lines to enter new more-sparsely populated frontiers, together with improvements in tank-wagon hauling range, has doubtless contributed to the present trend.

The data on installed horsepower per million barrel-miles pumped do not show any significant trends. This is not surprising, however, as the tendency to provide spare equipment, the increase in working pressures, the increasing station spacing, and the capacity of the lines in relation to their present throughputs are all contributing factors and working in opposite directions.

The great increase in the use of protective coating is due not only to the newer lines' coating a greater percentage of their pipe mileage, but to the coating of older lines during reconditioning as well.

Two Decades

And so the products pipe line industry approaches the 20-year mark in its continuing program to serve the petroleum consumer. Larger pipe, higher pressures, greater station spacing, and a willingness to accept and adopt technical advancements—all are contributing to the industry's pattern of growth not only in scope, but in efficiency as well.

Conclusion

In conclusion, the writer would like to thank the entire industry most heartily for its support of the questionnaire circulated. Without the excellent response to this questionnaire, our job in tabulating the data herein presented would have been impossible. Appreciation is extended to Mr. John G. Underhill, engineer with the Tuscarora Oil Company, Ltd., for the splendid assistance in correlating the data presented in this paper.

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Effect of Oil Proration on Marketing Flare Gas*

Changes in Oil Allowables Often Result in Sudden and Sharp Increase or Decrease in Gas Supply. How Does Pipe Line Handling Meet This Situation?

PAUL KAYSER†

THE EFFECT of proration orders on the problem of marketing of "flare" gas may be very clearly illustrated by comparison with the problem of a juggler juggling five glass balls in the air at one time while someone standing beside him snatches one of the balls out of the routine every few minutes and then tosses it back again. He must be pretty quick not to drop them all.

Just as the the pipe line has its schedules of deliveries arranged so that its market demands can be satisfied, the commission cuts allowables on oil and 50,000,000 cu ft per day goes off the line. This usually occurs in the winter when the gas is most needed. Then, when provision is made for this reduction and the system is running smoothly again, the allowables on oil are increased and 50,000,000 or 60,000,000 cu ft per day are added to the load. And this usually comes in the summer when it is not needed.

The difficulty is inherent in the problem because of the simple fact that the *market demand for oil* determines the quantity of flare gas available and *not the market demand for gas.*

To meet this situation and market anything like the gas available requires two things: (1) The construction of field lines, compressor stations, and treating plants sufficient to market the reasonable maximum quantity of gas that will be available under maximum production of oil, and (2) the construction of gathering lines, compressor stations, and treating plants sufficient to connect with an adequate supply of so-called dry gas *not* associated with oil so that the take from these sources can be increased to fill the gaps caused by the decrease of flare gas arising from the proration orders reducing the allowables on oil and can be correspondingly decreased when such gas is again made available by proration order increasing the allowables on oil.

This obviously entails extra capital costs. But there is no way to avoid such costs except to take the minimum of gas that will be available under proration orders and burn in flares the excess. This is wasteful and should be avoided to the extent it can be done within unreasonable capital costs.

It is not practicable to market every cubic foot but it certainly is not sound conservation policy to market only the minimum quantity. A sound informed judgment must be exercised to the end that the maximum quantity be taken that can be marketed at a fair price to the public.

The whole problem is further complicated by the fact that in order to market any substantial quantity of flare gas a pipe line must have available sufficient dry gas reserves to cover its peak requirements because flare gas cannot be cut back in the summer and increased in the winter but on the contrary is generally available in larger quantities in the summer than in the winter.

The company with which I am associated marketed an average of 440,000,000 cu ft of "flare" gas a day in 1949 and expects to market approximately 625,000,000 cu ft in 1950, and this figure should exceed 750,000,000 cu ft in 1951.

In order to cover peaks and to provide for change in quantities of gas available because of proration orders this company has provided capacity of 200,000,000 cu ft per day of "dry gas" available at all times and, under certain conditions, the capacity may be increased to 250,000,000 cu ft per day.

But this capacity alone is not sufficient to permit the marketing of anything like the reasonable maximum of flare gas available. So, in order to cover this deficiency, the company has made application to the Federal Power Commission for a certificate to build a 24-in. line to the San Juan Basin of northwestern New Mexico for the purpose of providing an additional peak delivery capacity of 167,000,000 cu ft per day.

To give maximum flexibility to the use of this capacity so that it can be turned on or off at will, the company has, subject to favorable action by the commission on its pending application, contracted to buy the leases covering gas reserves sufficient in the main to cover deliveries to be made from this area. The company is acquiring a number of gas wells with the leases and proposes to drill such additional wells as may be necessary to make the required deliveries. The line will be operated to cover peak demands and to cover deficiencies in quantities of flare gas due to proration orders of the Texas Railroad Commission. It will deliver as much as 167,000,000 cu ft per day in the winter and as little as 20,000,000 cu ft in the summer. It will make possible the operation of the 26-in. and 30-in. lines from the Permian Basin of West Texas to California at 95 to 97 per cent of capacity both winter and summer and the marketing of approximately 20,000,000,000 cu ft of flare gas during the summer months that heretofore has been burned in flares in the oil fields. This quantity of gas is roughly equivalent to 3,300,000 bbl of fuel oil and is a clear gain to the national economy.

The plan of operation permits the marketing of the maximum quantity of flare gas in the summer months,

The author, Paul Kayser, president, El Paso Natural Gas Company, when he spoke before the Southern Gas Association.

Presented before Southern Gas Association, Galveston, Texas, March 27-29, 1950.

†President, El Paso Natural Gas Company.

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We believe this plan for the marketing of the maximum quantity of flare gas is constructive and is a contribution to the solution of a problem in which we are all interested.

Cooperation Required

One of the things I want to bring most forcefully to your attention is the fact that there are a number of difficulties involved in the marketing of flare gas that can most certainly be remedied by cooperation—cooperation between the pipe line company, the gasoline plant operator, the producers, and the regulatory commission.

The first of these difficulties is the matter of daily operation of wells. A few illustrations will make this clear. At times we receive little or no gas from a given plant at night and by nine o'clock in the morning the plant may be delivering to us at the rate of 20,000,000 cu ft per day. We generally have a fluctuation from night to day of as much as 60,000,000 cu ft.

The second is the matter of monthly operation. Under proration orders fixing producing days at 20 days per month, we may have as much as 100,000,000 cu ft of gas a day cut off during the last 4 or 5 days of the month. This is wholly unreasonable and some means must be found to correct this situation. We realize that the producers are under the necessity of making their allowable each month and, consequently, the tendency is to avoid running too close to the end of the month because of the danger of losing some part of their allowable. We likewise understand, from the standpoint of the commission, the difficulty involved in permitting in normal operation allowables to be exceeded in any one month or deficiencies made up in any succeeding month. But these difficulties are not without their solution.

Efforts are being made by the producers to work out in various fields the staggering of production of wells so as to permit a more even flow throughout the month. Some progress has been made along this line but it has been difficult to obtain any uniform agreement to a plan. It may require a full scale hearing before the Texas Railroad Commission on each field and the promulgation of appropriate rules covering the matter before a satisfactory solution is found. The point I want to drive home here is that we must all look at the whole problem and genuinely cooperate to effect its solution. It is obvious that if, to the difficulty inherent in reduction and increase of quantities of flare gas available due to proration orders, there must be added a wide daily and monthly fluctuation in the quantity available then such operation must materially reduce the efficiency of any marketing program and greatly increase the waste of a national asset much needed both for domestic and industrial use.

However, the problem is comparatively new and we are fully confident from the progress already made, that, through the cooperation of all parties including the regulatory commission, ways will be found to solve in a satisfactory manner these operative difficulties.

In conclusion on this point we want to leave one set of figures on your minds so as to fix in your attention the value of the whole subject. The marketing of 750,000,000 cu ft of flare gas a day is equivalent to 125,000 bbl of oil per day or 45,620,000 bbl per year. This is a lot of value heretofore going to waste and a stake for our whole national economy worthy of everyone's efforts.

Proration of Gas

In the beginning I want to say that from an operation standpoint, the difference in marketing dry gas under proration orders applicable to gas and marketing flare gas under proration orders applicable to oil is about the difference of driving on a new country road and a paved highway.

In the case of the proration of gas, the market demand for gas determines the quantity to be produced whereas in the case of flare gas it is the market demand for oil that determines the quantity of gas that is available. But from a legal standpoint, there are many serious difficulties that will require a great deal of thought and care to find the correct solution. The first of these is the fact that long-term contracts for specific quantities at specific prices made with producers must be respected. The great network of pipe lines that has been built in the last 20 years has almost without any exceptions been built upon long-term, large quantity contracts for the purchase of gas at definite prices for definite periods. To disregard these contracts is in effect to pull the foundation out from under the industry. It is morally, economically, and legally wrong. In the first place, the states are unable to abrogate these contracts because of the provision in the Federal Constitution against the impairing of the obligation of contract by a state law, but if such were not the case, these contracts should be respected because it is true such contracts have made possible the phenomenal expansion of the industry.

The solution is not as easy as it sounds, however, because necessarily the full enforcement of these contracts frequently runs directly counter to the best interest of other producers in the field and can easily produce grave inequities. In fact, any fixed amount of production attributable to a given contract must necessarily hamper, to some extent, any rule for ratable taking from a given pool.

In addition, differences in prices to be paid under long-term contracts and short-term contracts may lead to dissatisfaction on the part of producers. Likewise, the differences in prices due to fluctuation of the market from time to time may produce apparent hardship. We must all realize that probably no perfect solution to these matters can be found and I believe we will have to be content with such proration orders as attempt to do equity as far as may be done without violating contracts that are the foundation of the industry. * * *

Natural Gas Survey

Natural gas may soon be available to "every major city in the United States," according to a study made by the Gas Appliance Manufacturers Association and based upon data made available by the Federal Power Commission. The study indicates that the principal impact is and will be along the Eastern Seaboard, with every major city from Maine to Florida eventually receiving natural gas.

During the 4½ years, July 1, 1945 to January 1, 1950, the FPC authorized construction including 26,513 miles of natural gas pipe lines, costing a total of $1,682,000,000, according to the survey.

Despite the fact that 1948 and 1949 established new records in FPC authorizations of natural gas pipe lines, applications pending February 1 "provide for an aggregate increase of 4,700,000,000 cu ft of natural gas a day." During 1949 the Commission authorized construction of 7537 miles of lines, costing $600,000,000.

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Stanolind's Turbocharger Experience*

F. V. COOK†

ALMOST 20 years ago most of us read with interest of the progress that was being made in Europe in supercharging 4-cycle diesel engines. Dr. Buchi had applied his early gas turbine experience to turbocharging and patented the principle of using multiple exhaust pipes and increased overlap of intake and exhaust valve opening that has been so successful all over the world. Most new 4-cycle diesel engines in sizes over 500-hp are now Buchi supercharged, although the high pressure system similar to that used in aviation is now coming into prominence for use on high duty diesel engines where reduction of space and weight is important. These are fitted with both single and multiple exhaust pipe systems between the engine and turbocharger.

About 1935 both The Cooper-Bessemer Corporation and the American Locomotive Company purchased Brown-Boveri superchargers for a factory test of Buchi supercharging, and in February, 1936, the Stanolind Pipe Line Company purchased one for installation on a 4-cycle, 16½-in. by 24-in. Alco engine. Cooper-Bessemer installed its two-inlet machine on an 8-cylinder engine and was very much discouraged with Buchi supercharging until results obtained by use of the two-inlet turbocharger on the 6-cylinder Alco engine became known. Both engine manufacturers obtained surprising results when the two-inlet machines were installed on 6-cylinder engines, and four-inlet turbochargers have since become standard for 8-cylinder engines.

The Stanolind Pipe Line Company's first turbocharger was placed in service in October, 1936. It was run at the unsupercharged rating of the engine for 49 hr, after which it was loaded to 125 per cent of normal rating for four hours before failure of the ball thrust bearing in the supercharger. It was fortunate that this supercharger was installed on a spare engine at a time when spare equipment was available. This engine was kept in service all the time the supercharger was not being repaired until February, 1941, at which time it had been in service 10,283 hr, or approximately 35 per cent of the time. It is interesting to note that this turbocharger was purchased to increase the output of the engine from 77 to 97-psi bmep, or 25 per cent.

During this period Alco had built several Buchi supercharged engines for railway service, and we at Stanolind believed that supercharging could be economically applied to our business because the pumps required little or no changes to absorb the increased engine output. Two additional superchargers were authorized during 1940. One of these was purchased from the American Locomotive Company, which was by now manufacturing superchargers, and the other, a Brown-Boveri machine, was purchased from Busch-Sulzer Bros.-Diesel Engine Company. Both were fitted with sleeve bearings and gave no mechanical trouble, but the installations were unsatisfactory due to incomplete scavenging of one cylinder. This was the result of placing two-inlet machines on 5-cylinder engines.

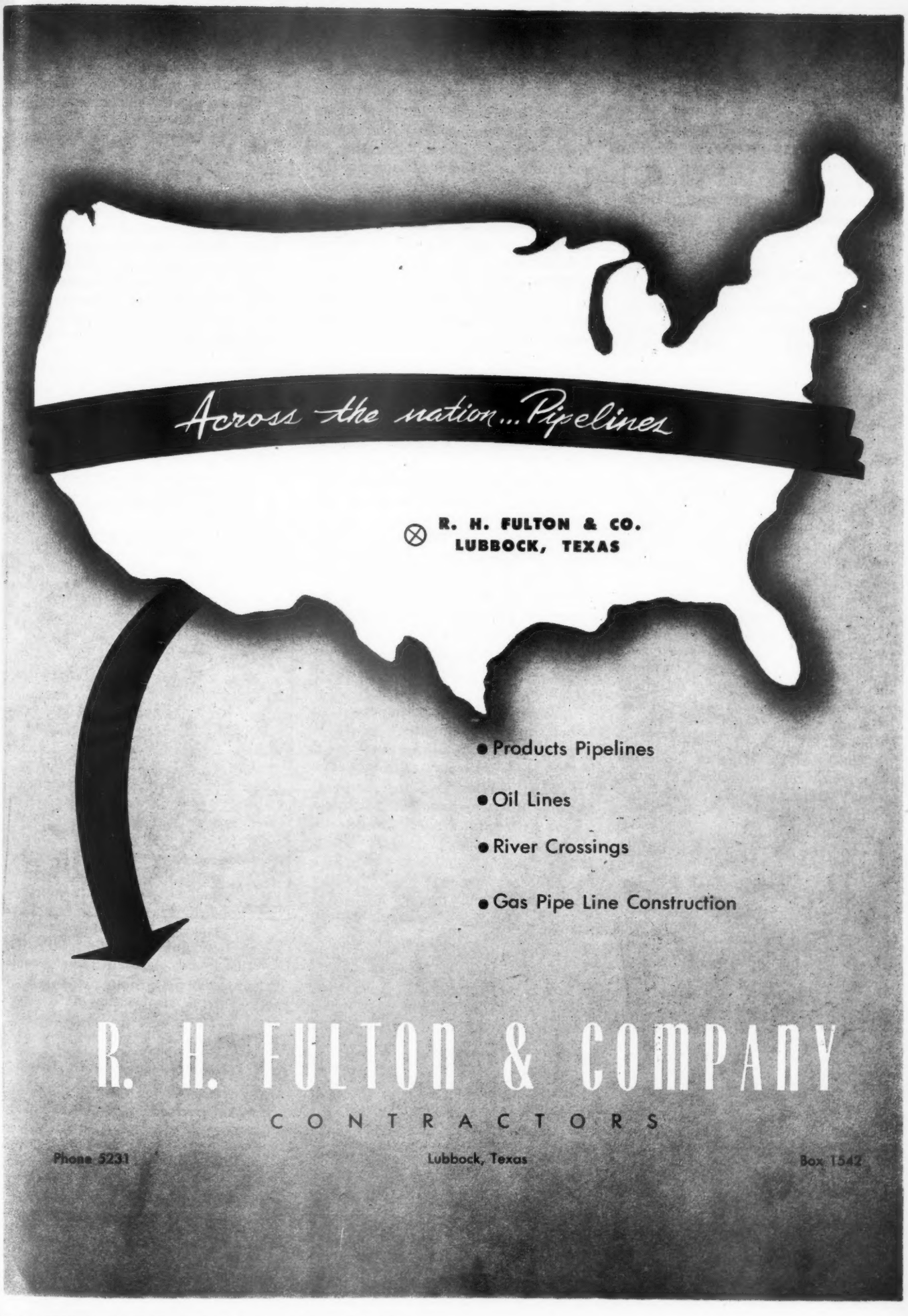
By the end of 1941 these two installations had been in service 13 and 16 months, respectively, and operation was satisfactory except for the interrupted scavenging, which we were certain could be corrected by using turbochargers with three inlets. At this time engine deliveries were slow and it was almost impossible to buy them for pipe line service. Turbochargers were being built in the United States by the Elliott Company and could be purchased for reasonable delivery, and appurtenances and piping could either be purchased or manufactured in our own shops. We needed only additional power to increase our pumpings because our previous line capacity increase was obtained by laying sufficient pipe to handle refinery requirements at 500-psi line pressure. Eleven superchargers were installed between May 1 and November 20, 1942. By the end of the war 37 had been installed on old engines, all except one, which was more than 20 years old. All but two of the superchargers had been installed on the main line from Freeman to Chicago, where the line pressure was increased in successive steps from 500 to 750 psi without additional machinery. This pressure increase required an 84 per cent increase in output of the engines, a large part of which was obtained by supercharging. All 16½-in. by 24-in. Alco engines were torsiographed and modified to increase their speed from 200 to 225 rpm and the speed of all Fulton engines was increased from 164 to 200 rpm. The speed was also increased on four 5-B-100 Busch-Sulzer engines. Generator loads were allocated to certain engines and the oil pump plungers changed to fully load all other engines.

Since the end of the war, increased refinery requirements have made it necessary to lay additional pipe and ten more engines have been supercharged. We have also installed six 800-hp supercharged engines, fifteen 1500-hp supercharged engines, and two 2000-hp supercharged engines during this period. This makes a total of 70 Buchi supercharged engines now in service over the system.

We have eight 6-cylinder, 17½-by-24-in. engines with Price injection that were purchased to develop 750-hp at 70 psi bmep. This type engine was previously built with 17-in. bore and developed 600-hp at 64 psi bmep. We were never able to develop continuously more than 685-hp with these engines since they were supercharged. This actual increase of 275-hp cost approximately $9750 per engine, or $35.50 per horsepower. Other installations where it was possible to obtain a full 50 per cent increase on engines of similar size were slightly less expensive on a horsepower basis, while some supercharging jobs on smaller engines, or where it was necessary to change pump gears, have cost approximately $50 per horsepower. This compares with approximately $250 per horsepower for the installation of new diesel-engine-driven pumping equipment. The cost of supercharging is low because no additional foundation, cooling system, building, or manifold piping is required, and there has been no great increase in cost since 1941. New exhaust and intake piping fabricated in our own shop for installation in the field costs $1500 to $2000 per unit. The water jacketed multiple exhaust piping between the engine and

*Presented before The American Society of Mechanical Engineers, Oklahoma City, Oklahoma, under the title, "Turbocharger Experince of the Stanolind Pipe Line Company.

†Master Mechanic, Service Pipe Line Company.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turbocharger alone will cost this much when purchased from firms specializing in this work. The turbochargers cost $2900 or $4200, depending on size, and license fees and tax, on a horsepower basis, cost from $900 to $1600. We have designed cams and fuel pump parts and had them made in various shops when the engine manufacturer's engineering facilities were not available for this work.

We can notice no difference in the cost of operation of the engines that have been supercharged except maintenance of the superchargers themselves. This cost has been less than the cost of maintaining additional cylinders, especially since 1942 when we standardized on the use of high lead bronze bearings in the turbochargers. We have lost only one turbocharger rotor since this change and it was burned up because the crew again started the engine after the supercharger stopped due to lubricating oil pump failure. We have changed a few of the old style, noisy turbochargers to avoid purchase of parts for these obsolete machines, but most of the superchargers installed in 1942 are still in service. One of the two purchased in 1940 is still in service and the other is in good mechanical condition and will soon be reinstalled on a 4-cylinder engine.

It is the writer's opinion that it would be to the advantage of most pipe line companies to supercharge old engines in locations where the additional power could be used, either for continuous operation to increase output or to provide space capacity.

There is every evidence that supercharging has not approached its ultimate perfection, either by the Buchi system or the single pipe system. Engines operating at 150 psi bmep are being offered with both systems. These increased ratings are obtained primarily by improved supercharger efficiencies at the higher charging pressures and by cooling the supercharger discharge air. ★ ★ ★

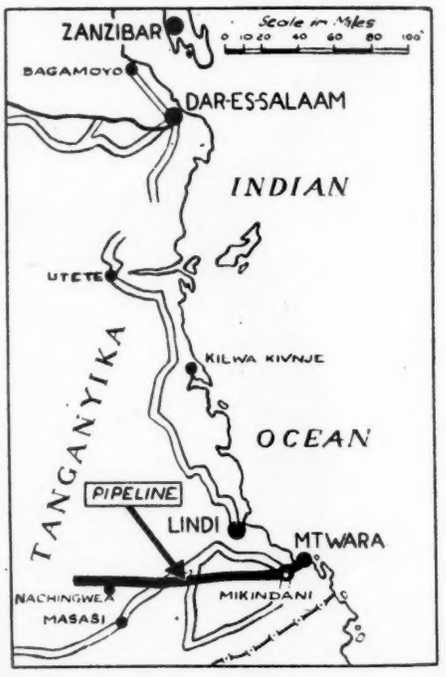
East African 130-Mile Pipe Line in Operation

Since Sir Edward Twining, Governor of Tanganyika, opened the valves of the 130-mile pipe line, supplies of petrol and gas oil have been flowing through the line to the groundnuts scheme in Southern Tanganyika.

This 6-in. pipe line runs from Mtwara on the coast to the heart of the groundnuts area, 20 miles west of Nachingwea. To insure easy detection of any leaks it is supported just above the ground on logs. As a safeguard against ruptures occurring due to temperature changes the pipe line is "snaked." It took 21 months to lay the line, mainly owing to difficulties of terrain, steel shortages, shipping delays, strikes, and lack of adequate landing facilities.

Bulk storage tanks are situated at Mtwara and at the inland terminal, and a pumping station, 45 miles west of Mtwara. Maximum pumping rate for petrol is 26 tons per hour and 30 tons for gas oil. Oil products thus take six days to reach the inland terminal from Mtwara. In addition to meeting the liquid fuel needs of the Overseas Food Corporation, the pipe line will be used to move gas oil and petrol to other users and so prove an asset in the economic development of the area.

Construction was supervised by Shell under the direction of J. M. Imrie, a 58-year-old Scot, who with other Shell technicians, brought experience of similar work from such diverse regions as Ecuador, Venezuela, West Africa, Suez, the Far East, and Australia.



Map showing new pipe line in East Africa to serve groundnuts (peanuts) area.

His Excellency, Sir Edward Twining, K.C.M.G., M.B.E., Governor of Tanganyika, performing the ceremony of opening the pipe line from Mtwara to the groundnuts area by turning the valve. J. M. Imrie is on the governor's right and on his left is G. T. Box, assistant general manager of The Shell Company of East Africa.

Reproduced by courtesy of the Public Relations Officer, Tanganyika Territory.

The Individual on the Job*

What Are the Factors That Must Be Considered by the Employer to Assure His Employees of Being Happy at Their Work and Willing to Give Their Best Efforts?

M. V. COUSINS†

IN A day and at a time when we regularly see such headlines as "Ninety Thousand Chrysler Employees Strike," "Two Hundred Fifty Thousand Telephone Workers Threaten Strike," "Three Hundred Sixty Thousand Miners on Strike," etc., it is easy to overlook the fact that in every case we are talking about individual people.

With the group thinking and the group action that has become a part of our modern industrial world, the individual, with his hopes, his ambitions, his needs, and his fears, is almost lost.

The individual has characteristics that make it essential to consider him individually, to work with him individually, to help him individually, if that individual's employment is to be satisfactory to him and if he is to give his best services to you.

In this country, up to about the turn of the century, there was usable free farming land. A high percentage of the population lived on farms and the younger generation growing up could and usually did start its economic life on some of this available free land or from the cheap and easily bought surplus of others, or from a division of the family's land. A few people were employed in public work, a few were tenant farmers, and a somewhat larger number were merchants and professional people.

The percentage of self-employed was high — relatively few people worked for others and many of those who were employed had accepted that employment only to procure savings with which to buy farms or businesses. With the development of the steam engine that gave us power and the cotton gin, and other mechanical devices that indicated the possibilities of mechanical inventions, there began a period of rather rapid change. The rate of this change was increased very greatly with the invention of the electric generator, copper wire conductors and motor combination that gave us real flexibility of power application. Manufacturing establishments were begun as small units and with time became larger and larger. The increased output due to improved manufacturing processes lowered prices so that more people could buy and hence more people were needed in manufacturing and service establishments. There has been a continuing increase in the percentage of our population who were employed by others, this increase being at the expense of fewer and fewer on the farms and otherwise self employed. A younger generation growing up is no longer predominantly self-employed but rather enters the employment of others when they begin their economically independent life.

As the size of our manufacturing units grew, many to enormous size, it was only natural that the individual employee received less and less attention. The original owners of the businesses were forced to employ managers when the size of the units became large, and these managers were very involved in meeting competition, improving manufacturing processes, etc. The individual employee received less and less attention and the attention he received was often based on expediency rather than on a long range plan of thinking, and decisions were made that were often arbitrary rather than well thought out and equitable. There was much in this situation that was not good or fair to the individual employee and at least partially as a result large unions became the companion piece of large employers.

I am one of those who believes that the future of good employee relations depends very largely on we as employers finding ways and means for the individual employee to achieve the fundamental needs for himself and his family with the real satisfaction to himself that he once would have attained working for himself on his own farm or in his own business. I do not believe I need argue that this is becoming more important.

My purpose today is to point out to you a few areas of thinking and action in which I believe there is real promise of improved relations with your individual employees on their jobs.

Place in Right Job

My first area of discussion centers around the job this individual is doing for you today; that is, his immediate work assignment. It is elementary to say that all of us want to do work that we can accomplish well and with confidence. If this is true, it means that we need make a very serious effort to place our employees in jobs that fit them.

Now I do not believe that there is one exact job that a man is best fitted for. I subscribe rather to the idea that there are general types of work that fit the man and there are other general types of work in which the man is a misfit.

In my company we have many jobs that require mechanical skill; that is, the mental ability to understand mechanical equipment and the physical dexterity to operate and maintain that equipment. It is almost a tragedy for a man to get into and continue in such a job if he has no inclination or ability to do mechanical work.

I believe that what I say of my company is generally true of the gas industry. We all have many mechanical jobs to be done and I suspect that most of us can recall instances where we employed persons for such jobs who were not competent and who did not become really competent. They were misfits—not because there was something wrong with them—but because they lacked aptitude for that particular work.

The same is true for other types of work; it is not limited to the mechanical field. You can probably call to mind clerical workers who have gone along year after year never bad enough to require dismissal, never good enough to be promoted. Tragically enough if we go back into such a man's early employment, it was usually apparent in the first few months he worked on the job that he lacked qualifications for the type of work he was doing. The opposite, and the condition that is of course more generally true, is the employee who is well placed in his work and who improves, does a good job, and goes ahead. Because of the fact that people are not happy in work they do not do well and therefore quit such jobs, I think

*Presented before the Southern Gas Association, Galveston, Texas, March 27-29, 1950.

†Director of Personnel, United Gas Pipe Line Company.

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this is the rule. There are enough exceptions, however, and they are sufficiently serious to warrant us working harder to place people in their proper types of work. Science, when we catch up with it, can probably help us materially but what will help us most right now is to use the knowledge and judgment we already have.

It is very seldom that the foreman or supervisor does not know within a few months of his employment whether or not a man is fitted for the work he is doing. I think we must realize that we are not doing the employee a favor by continuing him in such work but rather are risking serious long time injury to his best interests. Very often we are doing the man a favor by dropping him from the payroll if no work that fits him is available. I am afraid we are a party to the creation of personnel problems when we continue such a man in work for which he is not fitted.

By all means let's use the judgment and common sense we have, and get people into the kind of work they can do effectively for us and with satisfaction to themselves.

Employee Treatment

My second area of discussion relates to the treatment of the employee on the job. Now, we all want to be treated well, dealt with fairly and with dignity. This relates particularly to the treatment we, as employees, receive from our supervisors.

We all know we are employed to do the work our employers have for us to do. We expect to work; we expect to be supervised, directed, and instructed in that work, but we expect this supervision and direction by our superiors to be done in such a way that we retain our personal dignity, our self-respect.

The best supervisors are leaders not bosses. Unfortunately leadership is difficult to define and more difficult still to develop. In real life each of our supervisors is a combination of part leader and part loss. Some have more leadership, some have less. The development of those qualities of leadership that make for good supervision is not easy. The fact that it is needed, however, is shown by the conclusion of a great many persons who should know that most of our employee grievances and bad feelings develop through improper supervision.

If this is true, and I believe that it is true, then we need to make every effort toward the development of good supervisory qualities in our foremen. So much is easily agreed upon, but how to accomplish it is difficult and subject to many opinions. Many of us have attempted to develop programs that would improve the qualifications in our supervisors.

At the risk of repeating what all know, I would like to make a few suggestions in this matter of supervisory development. First, remember that the best training is training by example. If you, as a superintendent or executive, exercise care and judgment in supervising and directing the people under your supervision, they in turn will be likely to develop the same qualities in the direction and supervision of the people under them. Second, we should see that supervisors have opportunities to discuss ideas in regard to supervision. At the work level we expect our supervisors to react properly and almost automatically in critical situations. Certainly in every-day work there is not sufficient time for slow deliberate analyses.

Third, I would suggest you work to develop a real understanding among supervisors of the policies and philosophy of your organization. It is fairly easy to write a policy but it is not easy to develop real understanding. I believe that a great deal of talk and discussion is necessary to develop a real basic understanding of the philosophy back of that policy among the supervisors of any company.

One supervisory development method that seems to be very effective is to use foremen's meetings, planned foremen's conferences, etc., to talk out critical employee relation situations. From my experience, one value of such discussions of problem situations by people on relatively equal status, seems to be that members of the group are able to argue points of opinion and adjust their differences better than is done between supervisors and those under their supervision.

Our need is to develop our foremen and other supervisors within individual companies to the point that they act and react almost automatically along the same basic lines. It is extremely important that different foremen in an organization react similarly under similar circumstances. This can be accomplished only by having a close knit communicative group of supervisors.

Supervisory training and development and guidance must always be an important part of supervisory and executive training and we need to give it continuing attention.

Economic Advancement

My next area of discussion is around the fact that we all want to do better, to improve our economic situation.

This is normal and natural and to be commended. It is the basis of our American competitive free enterprise system. It is an important part of what has made America a great country and it must be encouraged.

Now there are two possible ways for an employed man to improve his economic situation. He may get more money for doing the same work he is now doing; or he may get more money for doing a better, a more responsible, a more difficult job. There are just these two possibilities—more for what is now being done or more for doing a higher rated job.

I think this is important and would like to discuss these two philosophies for a moment. The philosophy of getting more for the work now being done is a negative philosophy. It necessarily starts with the assumption that the employee is not getting what he now deserves. It means that someone has, to some degree, given him less than he justly should receive. One result of such thinking can easily be a determination not to give any more work than the short pay he is receiving justifies.

The philosophy behind getting more for doing a better, a more difficult, a more responsible job is a positive philosophy. It is basically giving more value of service in order for the employee to obtain a greater financial return. It is this philosophy, this thinking that has caused you, gentlemen and other leaders in our industry to progress to your present positions of responsibility. I believe that the development of this philosophy among employees is not only desirable but necessary if both the employee and his employer are to derive greatest benefit from their relationship.

I consider this to be so important that I would like to point out some of the elements that encourage the trend of thought toward doing a better and bigger job in order to obtain a greater financial return.

First, I believe that it is essential that the employee have a real opportunity for advancement. If there is no probability of an increase in income as a reward for doing a better job, if the possibility of promotion to a higher paying job is lacking, extremely few people will put their best efforts into their work.

Second, there must be enough additional pay for doing the higher rated, more difficult, more responsible job to make worthwhile the additional effort required of the employee to carry the additional responsibility.

Third, to be really effective, this opportunity for promotion must be on

a basis that the employee believes is fair to him. Some of the deepest seated grievances that I have ever known have been those that have resulted from a man's not getting a promotion that he felt he had a right to expect. The basis for the determination of who is to be promoted when there is a vacancy deserves far greater study than is usually given to it.

I believe there is one other element that is necessary in order to fully develop the thinking I have discussed. This is that the employee must be encouraged and assisted to develop himself. Most people do wish to develop their capabilities, but few can do this without outside assistance and encouragement. The methods of working toward the training, the education, the development of employees is an extremely important topic, one that I cannot cover now but do suggest that it be made a topic in our next year's Employee Relations Sections' discussions.

Security

My next area of discussion is around the fact that we all want and need to feel secure. As a country we may be over-sold on security to the degree that we are willing to see our government go too far in controls and taxation in attempting to attain that security. If this is true, it only illustrates and proves the fact that there is something basic in our desire for those things that we believe make for security.

I sometime doubt, however, whether we have given enough thought to the basic elements of real security. For example, I doubt whether we have thought and talked enough about the very real fact that it is probable that the greatest security any of us can have and yet maintain our freedom is to have a job and perform it satisfactorily in a successful company that provides a necessary and useful service for its customers. Certainly the gas industry is in this class and I believe we can assume that our employees are doing necessary jobs in a satisfactory manner, but I doubt whether most of us, and most of the employees under our supervision, properly appreciate the secure position we are in by virtue of the jobs we hold.

Security, however, is more than a job today, it is also protection against the future. While we can all take care of normal day to day situations, few of us can save enough to have sufficient income on retirement or to take care of emergency situations that arise from serious personal and family illnesses and accidents.

Before the development of this industrial age in which we are now living, family and community ties were stronger and food and shelter were not usually purchased totally from earnings. Furthermore, medical science and hospital facilities were not used to the degree they are today. Therefore, sickness was not the economic catastrophe it now is. I am sure we can all think of cases where savings have been wiped out and heavy indebtedness has been incurred through the serious illness of an employee or among members of his family.

The employee's protection from such events usually comes from programs that include plans for continuation of the employee's pay during serious illness and insurance against the heavier expenses such as that provided through group hospital and surgical expense coverage. These are rather well known and in rather general use in our industry. They have been discussed often in our employee relations sectional meetings and the various plans in use are rather well known.

While not too pleasant to contemplate, all of us will come to the end of our useful working days either through death or retirement. On our darker days, we wonder what will happen to our families if we should suddenly pass out of the picture, and on our brighter days, we look forward to retirement when we will be fishing, golfing, gardening, hunting, or whatever our fancy dictates to be a more desirable thing to do than work. Group life insurance and retirement plans are the solution to these two problems. They are not only desirable but in the present day and way of thinking almost essential.

I do not think I should leave this discussion without pointing out to you one other matter. Up to 10 or 15 years ago, most employed persons received all the reward for their work in their pay envelope. When a person left one job, his loss was usually only the loss of working time required to find a new job. In contrast to that situation, most of our companies now have several if not all of the benefit programs that I have outlined, all of which cease the moment the employee's services are terminated. In addition, we have all either consciously or subconsciously given very considerable weight to the element of length of service with our companies in making promotions, in continuity of employment when lay-offs were necessary, and in many other situations.

As a result, the tie between the company and the employee has tended and seems to continue to tend to become stronger with increased length of service. As employers we have wanted our employees to build up retirement and insurance benefits for themselves. We have wanted to assist employees and their families in times of stress, and have set up many of the benefit programs I have outlined, designed to so assist them. We have been human and helpful much to the credit of our companies. These things have gradually changed the employer-employee relationship to a remarkable degree. They have increased the employer-employee tie and have made his continued employment critically important to the employee. They have made the employee's tie to his employer so much more than a matter of a day to day or month to month relationship that most of our employees today consider their present employment to be a life time career matter. This is generally good and it is certainly to industry's credit. Having come to that point, however, we must recognize that the employer-employee relationship has become something of a familial relationship. It has a strong tendency to be continuing very much as the relations within a family are continuing. Under these conditions, a satisfied employee takes unusual pride in the success and in the achievements of his company. But also under these conditions, the employee who is dissatisfied with his employment does not quit his job as he probably would have done 10 to 20 years ago. Now he feels a strong compulsion to stay with his job and the benefits he has built up, and he often stays even if his situation is such that he is unhappy in his work. Several years ago, a friend, not an employee of a gas company, was grieving to me about his personal problem. He had a rather good job in a good company but certain matters had developed that made his work situation very difficult. After outlining these difficulties, he stated at length the benefits he had accrued in his company that would be lost if he quit his position. He added the matter up by saying that he just could not afford to quit. I have heard similar feelings expressed in a number of such situations.

As employers we have built up this tie with our employees in order to give them security. Having done this, we have the responsibility to both those employees and the owners of our companies to develop this into a friendly tie to the benefit of all parties. The employee must have satisfaction in his work, must receive recognition for his work, and encouragement to do better work. He must

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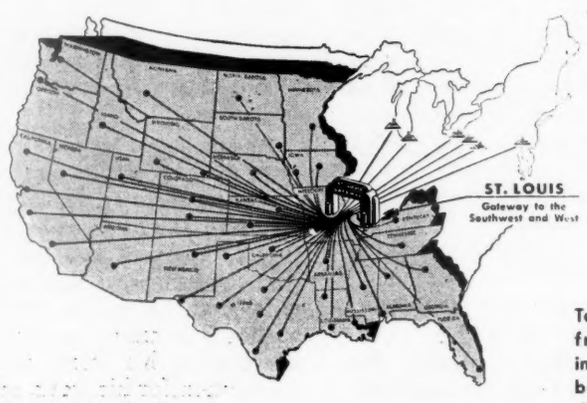

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have real opportunity for advancement. He must be allowed the opportunities that every one of us here in this room want and feel we have a right to expect. As supervisors and as executives, we must give serious consideration to this present day tie between the people under our supervision and our company as their employer. We must make very real efforts to help them to realize their wants and ambitions so that the employer-employee relationship will not become onerous or worrisome but rather pleasant and beneficial.

I would like before I conclude to take an optimistic view of our employer-employee relationships among the companies in the Southern Gas Association. I have been intimately acquainted with what has gone on in most companies in this area in the last 10 years, and have worked in the industry in this area for 25 years.

I am of the firm opinion that today we know more about our individual employees, their individual abilities, ambitions, and hopes than we have ever before known. I believe we are working harder to give good and continuous employment and opportunity for advancement. I believe that more and more attention is being given to the development of a top quality supervisory force. In turn I also believe that the employees of our industry are better satisfied, understand their advantages and possibilities of development better than ever before.

If I am right in these observations, then we are well on the road to increasingly better relations with our employees. But I think we must keep before us the fact that we have achieved our present situation only by very real effort toward bettering employee relations along with and as a part of our efforts toward improvement in our general operations.

In conclusion, I would like to offer the opinion that the future of our industry, possibly the future of our way of life, may depend on our ability as management, while successfully operating our companies in a regulated competitive economy, to build the kind of relations with our individual employees, on our individual jobs that will cause the sum total of these relations to be of such a nature that each individual employee will develop and progress within the limitations of his abilities, be secure within the limitations in which we can provide security, be well and fairly treated personally. If we will do this, we can expect to have the greatest of all securities—a willing, cooperative corps of fellow employees. * * *

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Use of Solid Adsorbents in Natural Gas Drying*

Performance of desiccants under variable conditions of velocity, humidity, and regeneration observed in tests.

E. P. WILKINSON‡ and B. J. STERK†

THE detrimental effects of water in natural gas are well known. Condensation of moisture may cause corrosion of pipe lines. Water may combine chemically with components of natural gas to form solid gas hydrates, compounds that are stable at high pressures, well above the freezing point of water. These solid particles tend to collect at constricted points in the transmission system, such as meters and valves, where they prevent efficient operation.

The means used to overcome these difficulties are varied. At the beginning of gas dehydration practices, calcium chloride lumps were used. For short distances, heating of the pipe lines may preclude hydrate formation. The use of inhibitors such as ammonia, acetone, and the lower alcohols may obviate the need for dehydration. Of more recent origin are the glycol liquidtype desiccants, with which dew point depressions of 55 F are reported.[1] The natural gas industry is, of course, well acquainted with the satisfactory dehydration obtained with the aluminum oxide base adsorbents. Dew points to — 104 F have been reported[2] with these solid type desiccants.

When Socony-Vacuum made available to industry its new solid desiccant, S/V Sovabead, it was only logical that the product should be considered for natural gas drying operations. Sovabead is a siliceous material, with high moisture adsorption capacity. In addition, the spheroidal form of the large beads gave promise of low resistance to gas flow and small pressure drops, while its strength and resistance to attrition seemed to indicate that there would be no dusting to impede gas flow in long-term operation. When the product was placed in commercial units it soon became apparent that it did indeed have promise in this capacity at high temperatures. It was reported to be unusually resistant to fouling by sour gases. Concurrent with field reports of these advantages, plant-scale controlled tests were conducted, and laboratory tests were set up to determine methods of using Sovabead to maximum advantage. The following material presents the results of these plant-scale and laboratory tests, as well as performance data from typical field units now in operation with Sovabead. This information is significant in design and operation of commercial drying units.

Plant-Scale Tests

Plant-scale tests were undertaken in order to determine, under carefully controlled conditions, the adsorption capacity of Sovabead when used as a dehydrating agent for natural gas under actual operating conditions, and also to effect a comparison with an established drying agent, activated alumina. The tests were conducted at the Seeligson natural gasoline plant operated by the Magnolia Petroleum Company at Premont, Texas. The drying unit, Type 35M-1000, manufactured by the National Tank Company, consisted of two towers, each containing about 6000 lb of desiccant. One tower was charged with Sovabead; the other, with activated alumina, Grade F. The unit was operated at a constant flow rate of 20,000,000 std cu ft a day, and each tower was regenerated when the dew point of the effluent gas reached 20 F. Pressures varied between 800 and 900 psig; temperatures between 75 and 90 F. Regeneration was effected at 360 F, and the regeneration stream, flowing at 1,200,000 std cu ft a day, was shut off when the effluent temperature of the regenerating gas reached 300 F.

The adsorption capacity of the desiccants was determined on the basis of the weight adsorbed to a dew point of + 20 F (dew points at the beginning of each cycle were below — 20 F for both desiccants). The results are given in Fig. 1, which at the outset shows a rapid loss in adsorption capacity for both adsorbents.

Following this period (12 weeks) of rapid loss in capacity, the Sovabead curve flattened out at 10-11 per cent adsorption capacity and remained at that figure until completion of the test, while activated alumina continued to lose capacity but at a slower rate. At the conclusion of the test, the adsorption capacity of the alumina had decreased to 3 per cent.

Pilot Plant Tests

In the course of the plant-scale tests at Seeligson some difficulties were experienced with excessive water in the early parts of the test. As might be expected, the water caused breakage of the Sovabead and appeared to cause caking of the alumina, thus excessive

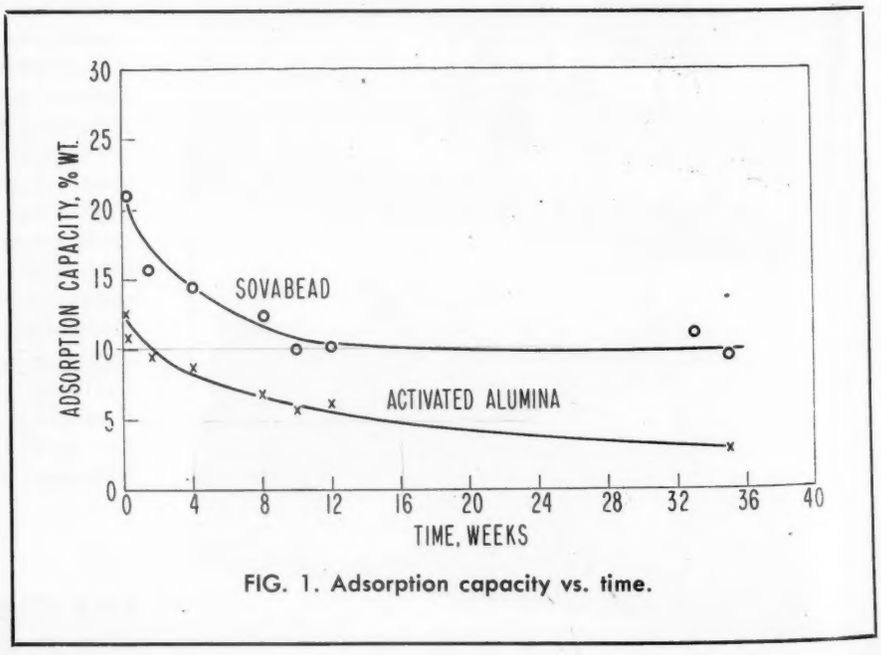


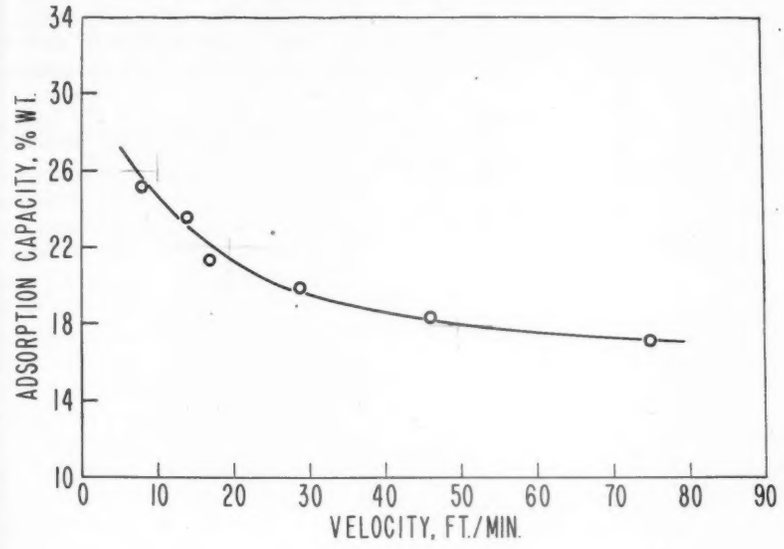
FIG. 1. Adsorption capacity vs. time.

*Presented before Spring Meeting, Natural Gas Department, American Gas Association, Tulsa, Oklahoma, May 8-9, 1950.

‡Magnolia Petroleum Company, Houston, Texas.

†Technical Service Department, Socony-Vacuum Laboratories, Brooklyn, New York.

FIG. 2. Adsorption capacity vs. velocity.



pressure drops through both desiccant beds were experienced until the operating condition was corrected. This condition had also been reported from some of the other field units already charged with Sovabead. Therefore, a laboratory pilot plant was set up and operated for about six months to determine the best methods of utilizing Sovabead and protecting it from deterioration. At the same time, at the request of manufacturers and operators of drying units interested in utilizing the high capacity of Sovabead, the effect of velocity on adsorption capacity was investigated. In addition, the effect of "relative humidity" of the influent gas on adsorption capacity was analyzed.

The laboratory apparatus consisted of a 15-ft tower 3 in. in diameter, fitted with appropriate thermometer wells, pressure taps, and condensate drains. The adsorbing tower also contained windows at 2-ft intervals along its entire length. The pressure during adsorption was maintained between 150 and 250 psig, while the influent temperature varied between 70 and 105 F. The unit was arranged so that regeneration could be carried out either concurrently (regeneration stream in the same direction as the process gas) or countercurrently (regeneration stream in the opposite direction to the process gas) at a pressure of either 200 or 800 psig.

Regeneration and Breakage

Particular emphasis in the pilot plant work was placed on the regenerative cycle as it was felt that the condensation of desorbed moisture was the cause of breakage. As anticipated, at 800 psig, it was possible to remove both gasoline and water from the top drains of the column, one of which was situated above the bed, and the other 6 in. below the top of the bed. At the higher pressure, condensation of water appeared on the upper windows of the tower, while at 200 psig no condensation of water was noted on any of the windows. At both pressures, gasoline appeared on all windows. Factors considered were the direction of regeneration flow, regeneration pressure, and length of adsorption cycle.

Test runs were made for 12 complete adsorption and reactivation cycles. At the conclusion of the runs the top third of the bed, where the bulk of the water and hence most of the breakage would be concentrated, and the remainder of the bed were separately screened. The percentage of desiccant passing through an eight mesh screen was conveniently taken as a criterion for breakage. The data from this testing (first four lines, Table 1) indicates that: (1) Countercurrent regeneration results in appreciably less breakage than concurrent regeneration (no breakage was encountered in the lower two-thirds of the bed), (2) greater breakage is experienced at the high pressure regeneration, and (3) the length of the adsorption cycle has little effect on breakage.

In none of these tests was breakage completely eliminated. Tests were then performed with a protective or buffer desiccant in the upper part of the tower. The buffer chosen was Sovabead W, a product of high mechanical strength coupled with high adsorption capacity at high humidity but with low capacity at low humidity. The substitution of this product for Sovabead at the top of the tower to the extent of 25 per cent of the bed depth eliminated all significant breakage, as indicated in the last two lines of Table 1.

TABLE 1. Effect of variables on Sovabead breakage.

Desiccant	Direction of regeneration flow	Length of adsorption cycle, hr	Regeneration pressure, psig	Breakage,* per cent through an 8-mesh screen
S/V Sovabead	Concurrent	8	200	8.3
S/V Sovabead	Countercurrent	8	200	3.4
S/V Sovabead	Countercurrent	8	800	4.0
S/V Sovabead	Countercurrent	6	800	4.5
S/V Sovabead plus Sovabead W	Concurrent	8	800	1.1
Sovabead W	Countercurrent	8	800	1.0

* New Sovabead analyzed 0.5 — 1.0 per cent through an 8-mesh screen.

Velocity and Capacity

Although previous work[3] in drying air at atmospheric pressure had shown clearly that the capacity of desiccants is affected by air velocity, no laboratory work has been done on this phase of natural gas drying. Therefore the pilot plant equipment was used to determine the capacity of Sovabead, which had been through 12 to 20 regenerations, at various gas velocities and a pressure of 200 psig. The results presented in Fig. 2 show that adsorption capacity increases slowly and quasi linearly with decrease in gas velocity from 80 to 20 ft per min and then increases sharply to the equilibrium capacity (38 per cent for new desiccant) as zero velocity is approached. A 50 per cent increase in adsorption capacity is obtained in going from 75 to 8 ft per min.

Humidity and Capacity

In most cases natural gas to be dehydrated is saturated with water vapor. However, there are instances where the gas has to travel long distances to the dehydration unit, and any increase in temperature of the gas in the long lines will be accompanied by a decrease in its "relative humidity." Under these conditions, any drying unit will suffer a loss in adsorptive capacity.

Pilot plant tests on the effect of

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TABLE 2. Effect of relative humidity on adsorption capacity of Sovabead.

Gas dried to effluent dew point, F	Adsorption capacity, per cent of desiccant by weight: Gas, 91 F saturated	Gas, 125 F 35 per cent rel. humidity
20	14	7
0	16	9
10	17	10
20	18	11

TABLE 3. Effect of inlet temperature on adsorption capacity of Sovabead.

Temperature of inlet gas, F	Adsorption capacity, weight per cent
65	10.2
75	10.2
85	10.3
95	10.2
100	10.6
105	11.6
110	11.4
115	10.8
120	11.6

relative humidity on the adsorption capacity of a gas were made with a gas saturated at 91 F and another saturated at 90 F but heated to 125 F to give a relative humidity of 35 per cent. The results given in Table 2 showing the relative desiccant capacity when drying these two gases to various dew points clearly portray the decreased adsorption capacities obtained at the lower relative humidity.

Field Performance

In addition to the investigations described, which required close control, it has been possible to obtain information from the operating data of various commercial units using Sovabead. These data bring out information concerning the effect of temperature on adsorption capacity and the effect of sour gas on adsorption capacity.

Temperature and Capacity

High inlet gas temperatures create operational problems regardless of the desiccant used. In the first place, for every 20 F rise in temperature the water carrying capacity of the gas is approximately doubled; thus, if the temperature of the influent gas is increased while maintaining a saturated state, a greater load is placed on the desiccant. In addition, at higher temperatures high molecular weight hydrocarbons including adsorption oils are dissolved in the gas stream and condense on the desiccant beds to cause fouling and reduction in capacity. The effect of temperature alone is reflected in the performance of the conventional desiccant, Florite, the adsorption capacity of which reportedly[2] varies from 10-15 per cent at 40 F to 3.5 — 5 per cent at 110 F.

To determine the performance of Sovabead at various temperatures, the data in Table 3 were obtained from two plants where operating temperatures varied over a considerable range. It will be noted that Sovabead retains high capacity at temperatures up to 120 F. Laboratory results have shown that dew points in the vicinity of — 45 F are obtainable at temperatures of 200 F with air at atmospheric pressure.

Effect of Sour Gas

The dehydration of sour gas is troublesome to operators. Although in many operations the gas is sweetened before drying, there remain other operations where the sweetening process is not economically feasible. In these latter cases the performance of the dehydration units on sour gas streams is of considerable importance.

In order to determine the performance of Sovabead in drying sour gas, data were obtained from a plant operating on a sour gas stream of such quality that the conventional desiccant, activated alumina, was effective for a very short time and was changed every 45 days on the average, with a maximum life of 60 days. The unit consisted of two towers operating at 5,000,000 std cu ft a day, 95 F, and 600 psig, with countercurrent regeneration to a maximum effluent temperature of 325 F. The gas contained hydrogen sulfide in quantities varying from 1800 to 2000 grains per 100 std cu ft. The gas, except for a conventional water scrubber before drying, was untreated.

One tower was charged with 4700 lb of Sovabead and 300 lb of Sovabead W; the second tower, with 5000 lb of activated alumina. After 40 days of operation, the data for a typical 24-hr period of operation were as follows:

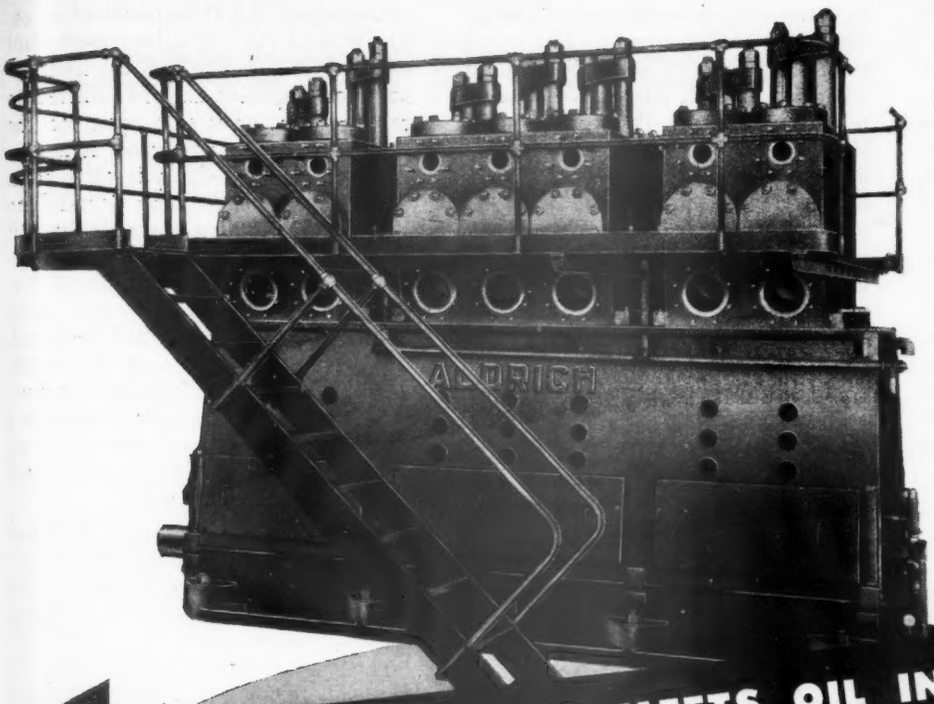
	Tower with Sovabead	Tower with activated alumina
Hours of adsorption...	18	6
Effluent dew point, F..	—20	+25

It is evident that the Sovabead tower is carrying some three-quarters of the load on the unit with excellent dew point depression, while the tower charged with activated alumina has decreased appreciably in capacity as evidenced by its short adsorption cycle and the relatively high dew point of the effluent gas.

The test was discontinued, but after 5½ months the Sovabead was still in use while the activated alumina had been replaced with S/V Sovabead.

Influence of Data

In addition to the obvious advantages of the bead-type desiccant in operations involving sour gas and gases at high temperatures, the foregoing investigations and data have practical significance in the operation of units



This 8½" stroke, 1900 hp Inverted Septuplex Pump was made for crude oil pipe line service and is designed for direct coupling to engine, motor or speed reducer. Illustration shows pump without suction and discharge manifolds. Request Data Sheet 67.

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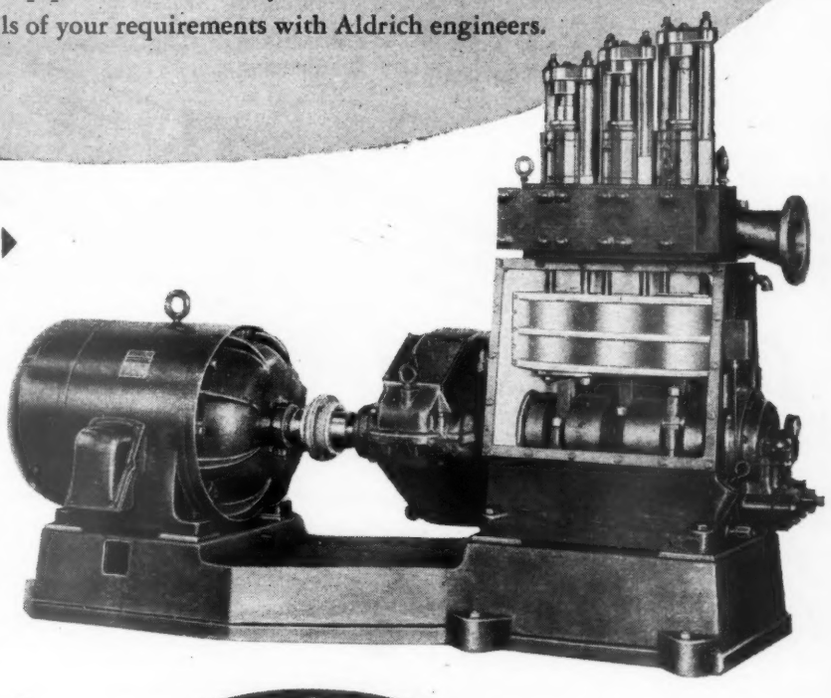

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under more normal conditions and in the design of new units.

A desiccant of high adsorption capacity permits the design of more compact and economical units. The adsorption capacity of 8 per cent, demonstrated by the controlled plant-scale tests and other supporting field data, as compared with the usual 5 per cent capacity for aluminum oxide-base adsorbents, makes possible savings in steel and insulating material. Such compact units will, of course, have the advantage of lower operating costs. In addition, the higher adsorption capacity realized at low velocities, as demonstrated by the pilot plant tests, leads to interesting possibilities of designing for large bed area and low velocities, particularly with Sovabead, wherein the high adsorptive capacity is further utilized. This aspect of design is now being realized in radial flow units, which are designed to introduce the gas around the periphery of a cylindrical bed of desiccant with the gas emerging from a hollow core in the desiccant bed. In this fashion, large bed area with attendant low velocity and high adsorption capacity is obtained in a compact unit.

High adsorption capacity in the operation of existing units is perhaps of more immediate interest. It has two advantages: (1) It increases plant capacity, and (2) when increased plant capacity is not required, the high adsorption capacity can be utilized to prolong the on-stream time of the desiccant. In the first case, it is possible, when desired, as it often is in these days of increasing demand, to step up the gas flow through the unit and thus increase plant capacity without the installation of additional drying units. In the second case, where additional capacity is not required, the adsorption cycle can be lengthened, and, thus, less frequent reactivation is possible. Since reactivation is a primary cause of loss of adsorption capacity, the overall life of the desiccant is appreciably increased.

Laboratory investigations show that methods of regeneration can be important in prolonging the life of the bead desiccant. In general, countercurrent regeneration is preferred; however, the use of a buffer desiccant is recommended to reduce breakage to a negligible level. Florite has been used successfully as a buffer in some installations;[4] however, Sovabead W is preferred because of its higher adsorption capacity (46 weight per cent at saturation).

Finally, the laboratory data underline the fact that in those cases where the influent gas is not saturated, lower adsorption capacity must be expected with any desiccant. In order for plants, operating under these conditions, to maintain plant capacity, consideration should be given to cooling the gas before drying so as to approcah saturation conditions where the desiccant will operate to maximum capacity. This procedure may well eliminate the necessity for additional units.

Conclusion

Significant differences in the performance of common adsorbent materials can be determined through the carefully controlled operation of a commercial drying unit. The accompaniment of this work by pilot plant tests permits more careful scrutiny of the performance of a desiccant under variable conditions of velocity, humidity, and regeneration. The data so derived combined with operating data from other commercial units can be used by designers of equipment and operators of natural gas plants in building more efficient units to obtain maximum plant capacity at minimum cost.

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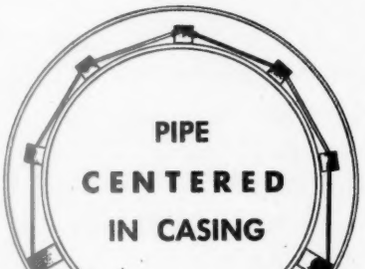

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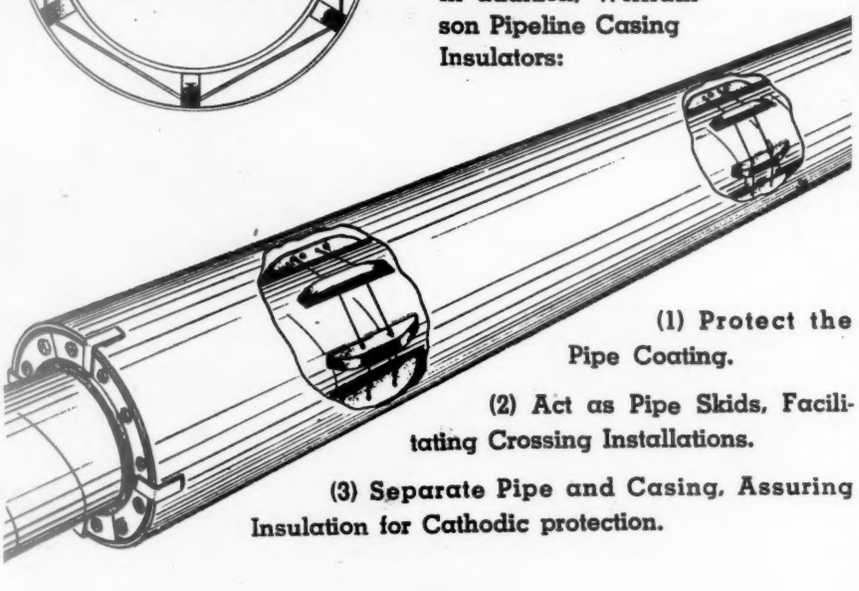

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Cathodic Protection on Texas Gas System*

Details of steps taken to protect from corrosion the 840-mile line from Texas to Ohio.

ROBERT J. KUHN†

Kentucky Natural

"Division No. 3 (of Texas Gas Transmission Corporation) formerly the properties of Kentucky Natural Gas Corporation began operation in 1929.[1] The system now consists of approximately 858 miles of pipe lines in western Kentucky, southwestern Indiana, and southeastern Illinois.

"The main pipe line of Division No. 3 (of Texas Gas Transmission Corporation) extends from a point approximately 25 miles north of Terre Haute, Indiana, in a southerly direction to a point near Evansville, Indiana, a distance of 129 miles. There it is reduced to a 10-in. line, which passes south and east into the western part of Kentucky and through that region to Portland, Tennessee. It interconnects with the pipe lines of Panhandle Eastern Pipe Line Company at two points, one north and one east of Terre Haute, with the pipe lines of Tennessee Gas Transmission Company at three points, Portland, Tennessee, and Scottsville and Glasgow, Kentucky, and with the pipe line of Texas Eastern Transmission Corporation near Princeton, Indiana.

"The daily delivery capacity of Division No. 3 aggregates approximately 85,000,000 cu ft."

The corrosion and protection activities on Kentucky Natural Gas Corporation system are not known in detail to the author but it is my understanding some studies and protective work had been done.

Generally speaking, the Kentucky Natural Gas System is in a fresh water country generally considered not so corrosive as the salty areas along the seaboards or as in the arid west. However, due to the presence of coal mines, seams and washes and other contaminations, there are undoubtedly corrosive conditions in the area served as well as in more recognized corrosive sections of the country.

Memphis Natural

"The Memphis Natural Gas Company system was started in 1928 with the construction of an 18-in. pipe line from the then practically untapped Monroe gas field in northern Louisiana to the city of Memphis, Tennessee.[2] The line was originally powered with compressor stations located at Monroe, Louisiana, and Benoit, Mississippi, and had a capacity of 60,000,000 cu ft per day. Sales during the first year of operations totaled 6,300,000,000 cu ft.

"To meet the continual growing demand for natural gas during the next 20-year period, new transmission lines and compression were added. In 1945 the company's lines were extended to the Lisbon gas field in northern Louisiana to supplement the original supply from the Monroe gas field.

"This system—Divisions No. 1 and 2 of the company—presently consists of 643 miles of pipe lines including two 18-in. lines which originate in the Monroe gas field, cross the Mississippi River at Greenville, Mississippi, and extend to Memphis, Tennessee, a distance of 211 miles. A single 10-in. line extends from Memphis 118 miles north to Jackson, Tennessee. In addition there is a 20-in. line 50 miles in length connecting the Lisbon gas field with the company's 18-in. lines in the Monroe gas field. The daily delivery capacity totals 209,000,000 cu ft."

In 1934, or six years after the construction of the 18-in. pipe line from the Monroe, Louisiana, gas field to Memphis, Tennessee, innumerable corrosion leaks occurred on the 18-in. line and the author was called in as consultant to handle the situation.

Cathodic protection was applied to less than a mile of very badly corroded 18-in. line in a low swampy section near Tunica, Mississippi, on October 23, 1934, and to date after 16 years and 5 months not a single, further corrosion leak has developed on this Dresser-coupled section despite the fact line pressures were increased from approximately 400 psi to approximately 500 psi, depending upon the season and loads.

The success of cathodic protection in preventing corrosion leaks and loss of gas and perhaps service on the small trial section led to the further application of cathodic protection to the pipe line facilities of old Memphis Natural Gas Company, now the Texas Gas Transmission Corporation, until at the end of 1949 there were approximately 525 miles of pipe line cathodically protected under the engineering guidance of the author out of a system total of 643 miles. It may be of interest to the reader to look over the corrosion leak record on the two 211-mile, 18-in. lines from the Monroe field to Memphis, Tennessee shown below:

Older 18-in. line constructed in 1928

1934	Numerous leaks. Cathodic protection installed on trial section.		
1935	Numerous leaks. Required 25 miles of reconditioning that had to be subsequently cathodically protected.		
1936	6 leaks	1943	3 leaks
1937	20 leaks	1944	8 leaks
1938	5 leaks	1945	11 leaks
1939	7 leaks	1946	2 leaks
1940	15 leaks	1947	3 leaks
1941	14 leaks	1948	2 leaks
1942	12 leaks	1949	0 leaks

211 miles of loop line, Monroe gas field to Memphis, Tennessee, begun 1940, completed 1946:

Not a single corrosion leak to date. March, 1950.

This record of not a single corrosion leak in 10 years on the ¼-in. wall loop pipe line in contrast to numerous leaks on the ⅜-in. wall original line in 6 years, is thought significant of the protection afforded by the cathodic protection process. Both lines were laid parallel in the same soils within 8 to 10 ft of each other.

Formation of Texas Gas

On April 1, 1948, Kentucky Natural Gas Corporation and Memphis Natural Gas Company were merged into one company, i.e., Texas Gas Transmission Corporation with headquarters in Owensboro, Kentucky. J. H. Hillman, Jr., was the first president of the new corporation with W. T. Stevenson, executive vice president, L. E. Ingham, vice president, and H. L. Mann, vice president.

On March 30, 1949, the Federal Power Commission authorized the new company to construct a new 840-mile, 26-in. gas pipe line from the Carthage gas field, Texas, to Middletown, Ohio, with numerous compressor stations along the route.

The new line was estimated to cost approximately $73,000,000 and was designed to initially deliver 304,000,-

*Presented before American Gas Association, Detroit, Michigan, April 3-5, 1950.

†Consulting engineer, New Orleans, Louisiana.

[1, 2] Taken from 1948 Annual Report of Texas Gas Transmission Corporation.

000 cu ft of gas per day with an ultimate capacity of 400,000,000 cu ft a day. Ten compressor stations were planned, six of which were to be constructed during 1949.

Upon completion of the new line, the new combined system including the new line would consist of 2400 miles of pipe line with a total capacity of 650,000,000 cu ft of gas a day.

The new 26-in. line was to deliver 120,000,000 cu ft of gas a day to the old Memphis Natural and Kentucky Natural divisions of the new company serving several cities and towns in northwestern Mississippi, Memphis, Jackson, and other places in western Tennessee; Owensboro, Bowling Green, Franklin, Madisonville, and other places in Kentucky; Evansville, Terre Haute, Bloomington, Columbus, and other places in Indiana.

The line was to ultimately deliver up to 235,000,000 cu ft of gas a day to Texas Eastern Transmission Corporation at the northern terminus of the line at Lebanon, Ohio, which gas was in turn to be delivered to the East Ohio Gas Company, The Manufacturers Heat and Light Company, and the Ohio Fuel Company.

The line was to traverse the red hills of Texas and North Louisiana, together with many rivers and bayous, some swift like the Red and Ouachita rivers and some sluggish like Bayou Macon and others. These were numerout flat swampy areas like in southeast Arkansas and the Mississippi Delta region between Greenville, Mississippi, and Memphis, Tennessee. Several large rivers like the Mississippi, the Tennessee, the Cumberland, the Green, and the Ohio, the wind deposited and badly eroded Loess bluff region near Memphis, the coal mine and coal blossom areas of Kentucky countryside around Louisville, and the farming and industrial country in Indiana and Ohio.

The line was planned to be welded from end to end but permission had been obtained to install insulated flanges at both the southern and northern ends of the line and in all laterals and in connections to the several compressing stations. Since the line was being designed for 850 psi operating pressure, the design of the insulating flanges, where designated, had to take into consideration this high pressure.

With a single high pressure gas pipe line of such huge diameter as 26 in., and with enormous loads depending for transmission on a sound pipe line, the matter of corrosion naturally arose. The corrosion question was made more pressing by the fact that the wall thickness of the pipe to be used was $\frac{9}{32}$-in., relatively thin wall pipe in contrast to the $\frac{3}{8}$-in. wall pipe used on the old 18-in. Memphis Natural main line, which carried a maximum pressure of 550 psi.

The working stresses per square inch on this pipe line, therefore, will be much greater than on older lines and it is a fairly well known fact that highly stressed metal has a greater corrosion rate than unstressed or lightly stressed metal.

The fact that this huge pipe line was to be continuously welded and was to pass through all kinds of soil formations indicated that the galvanic long line electric current effects would be most pronounced, especially between high, well drained, sandy and rock areas to low, badly drained or wet streams and flats caused mainly by the differential aeration of these environments.

Add to these factors the enormous differential aeration effect between the top and bottom of the pipe at a specific location. With 3 ft of cover on the pipe, the bottom of the pipe is more than 5 ft deep and from a knowledge of the rotting of fence posts it can be easily seen that considerable differences in aeration occur at 3-ft and 5-ft depth, especially in the dry months of the summer and fall. This differential aeration would set up highly active galvanic cells whose action would add to the long line galvanic corrosion effects as well as to local chemical effects of the soil.

In addition to the natural corrosive conditions to be encountered the manmade corrosive conditions generally called "electrolysis" and caused by stray currents from street railway or trolley buses from manufacturing plants, from other cathodically protected pipe lines or other sources had to be considered.

The decision reached was to clean, prime, hot coat with a coal tar bare pipe line enamel, wrap with a single layer of fiberglas and apply cathodic protection to the entire pipe line from Texas to Ohio. Some special precautions against specific situations were to be handled according to details to be described later.

"Pilot" Section

During the summer of 1948, as a matter of emergency for gas storage purposes, 63 miles of 26-in. line were constructed from Lula, Mississippi, compressing station, situated in the low flat alluvial and formerly swampy area of the Mississippi River flood plain generally known as the "Delta", to just east of the city of Memphis, Tennessee, situated in the high, hilly loess soil bluff country.

The line was planned by many of the company personnel in collaboration with Stone and Webster Company who handled the engineering and inspection and with the author who handled the corrosion and cathodic protection design.

The job was let in two sections, Spread No. 1 or 33 miles from Lula, Mississippi, compressing station to Banks, Mississippi, all in the low flat delta country, was awarded to the N. A. Saigh Company and the remainder known as Spread No. 2 or 30 miles from Banks, Mississippi, to Memphis, Tennessee, comprising 4 miles of delta country and 26 miles of hill country was awarded to the J. R. Horrigan Construction Company. Construction on both spreads began on the south ends of the respective spreads.

The pipe used was of 26-in. diam of $\frac{9}{32}$-in. wall and was formed from flat plate and longitudinally seam welded at the A. O. Smith plant. The pipe was not covered with any kind of mill primer or lacquer.

After welding in the field, the pipe was mechanically cleaned with a traveling W-K-M machine, immediately followed by priming with Pittsburgh Coke and Chemical Company coal tar base pipe line primer paint.

After the primer had dried, a traveling mechanical coating and wrapping machine applied a single coating of Pittsburgh Coke and Chemical Company coal tar base pipe line enamel followed immediately by a single wrapping of Fiberglas.

The enamel for the wrapping machines was preheated in 500-gal mechanically agitated tar pots.

The coating and wrapping were not tested with an electrical holiday detector but upon the writer's recommendation were given good "eye" inspection, especially before backfilling. No stress was laid on "holidays" but great emphasis was placed on patching large areas of coating and wrapping that may have been omitted by the machine or may have been damaged in handling or lowering.

As the line progressed, coating resistance tests on several isolated sections of both spreads Nos. 1 and 2 were made to gain some idea of the quality of the finished coating and wrapping job performed by the two contractors.

These preliminary tests[3] indicated that the coating and wrapping resistances on both spreads were running around 900,000 ohms per sq ft in the low lying and low resistance delta

[3]See "Report on Inspections and Tests Relative to Coating and Wrappings and Cathodic Protection on the New 26-Inch High Pressure Gas Pipe Line between Lula, Mississippi and Memphis, Tennessee," by Robert J. Kuhn, October 14-15-16, 1948. Published by Pittsburgh Coke and Chemical Company.

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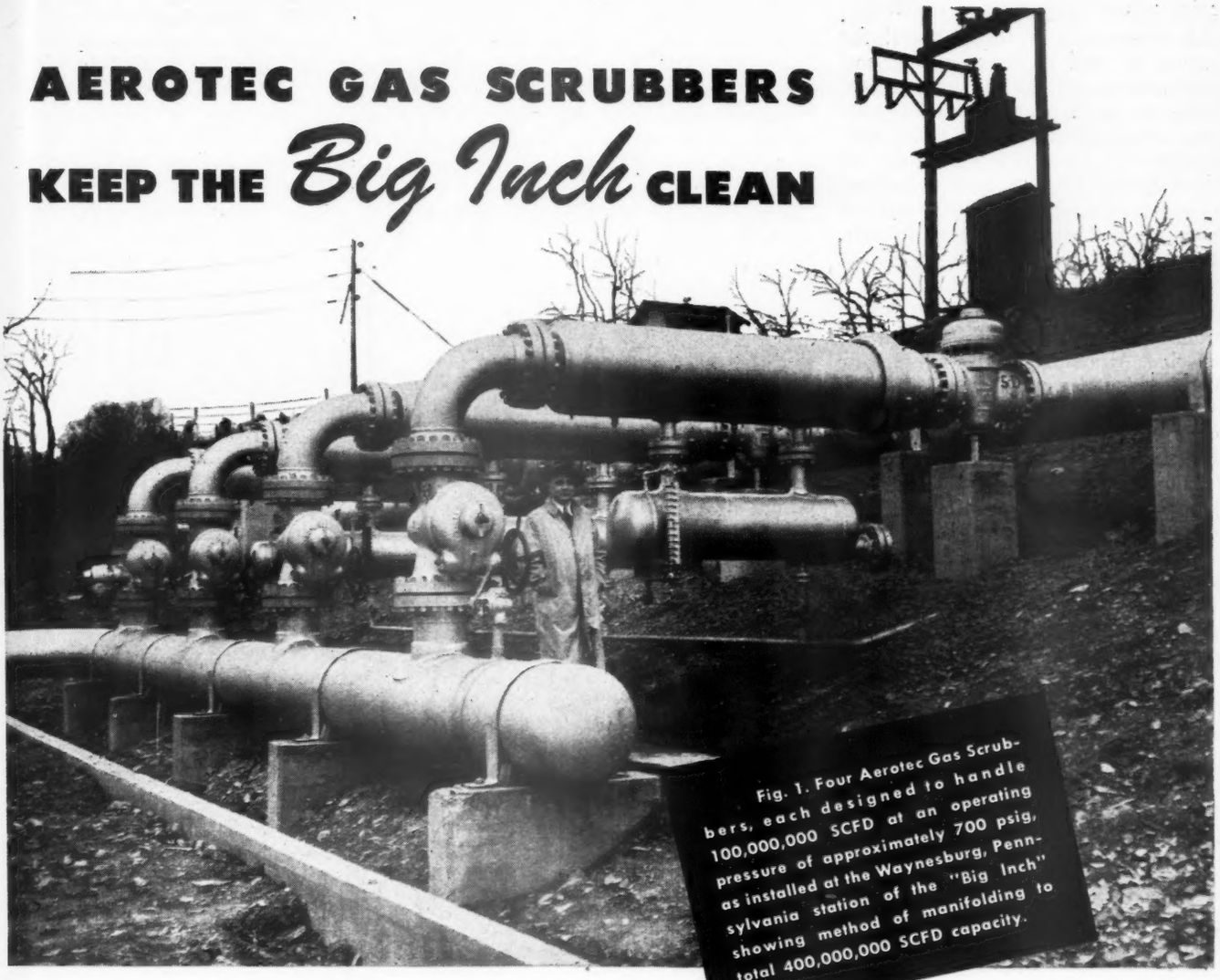

Fig. 1. Four Aerotec Gas Scrubbers, each designed to handle 100,000,000 SCFD at an operating pressure of approximately 700 psig, as installed at the Waynesburg, Pennsylvania station of the "Big Inch" showing method of manifolding to total 400,000,000 SCFD capacity.

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soils, values considered as excellent.

Indications were then, that if the entire 63 miles were coated and wrapped as well as the first several large test sections, the electrical current requirements for the line would amount to the amazingly low value of 0.000000444 amp per sq ft of surface or to a total of approximately only 1.0 amp, since there were approximately 2,230,000 sq ft of surface on the 63 miles of 26-in. line.

It may be well at this point to mention some details of construction on the line. All casings, vents, risers, and valves were cleaned, primed, and hot coated with the same materials as used on the pipes. The carrier pipes were kept insulated from the casing pipes by means of several layers of asbestos pipe line felt wrapped around the carrier pipe at spacings of 10 ft. The ends of all casings were sealed with Portland cement-sand grout.

River weights were of concrete rather than of metal and care was taken to reinforce the coating and wrapping under the heavy concrete clamps by means of an extra layer or two of pipe line felt.

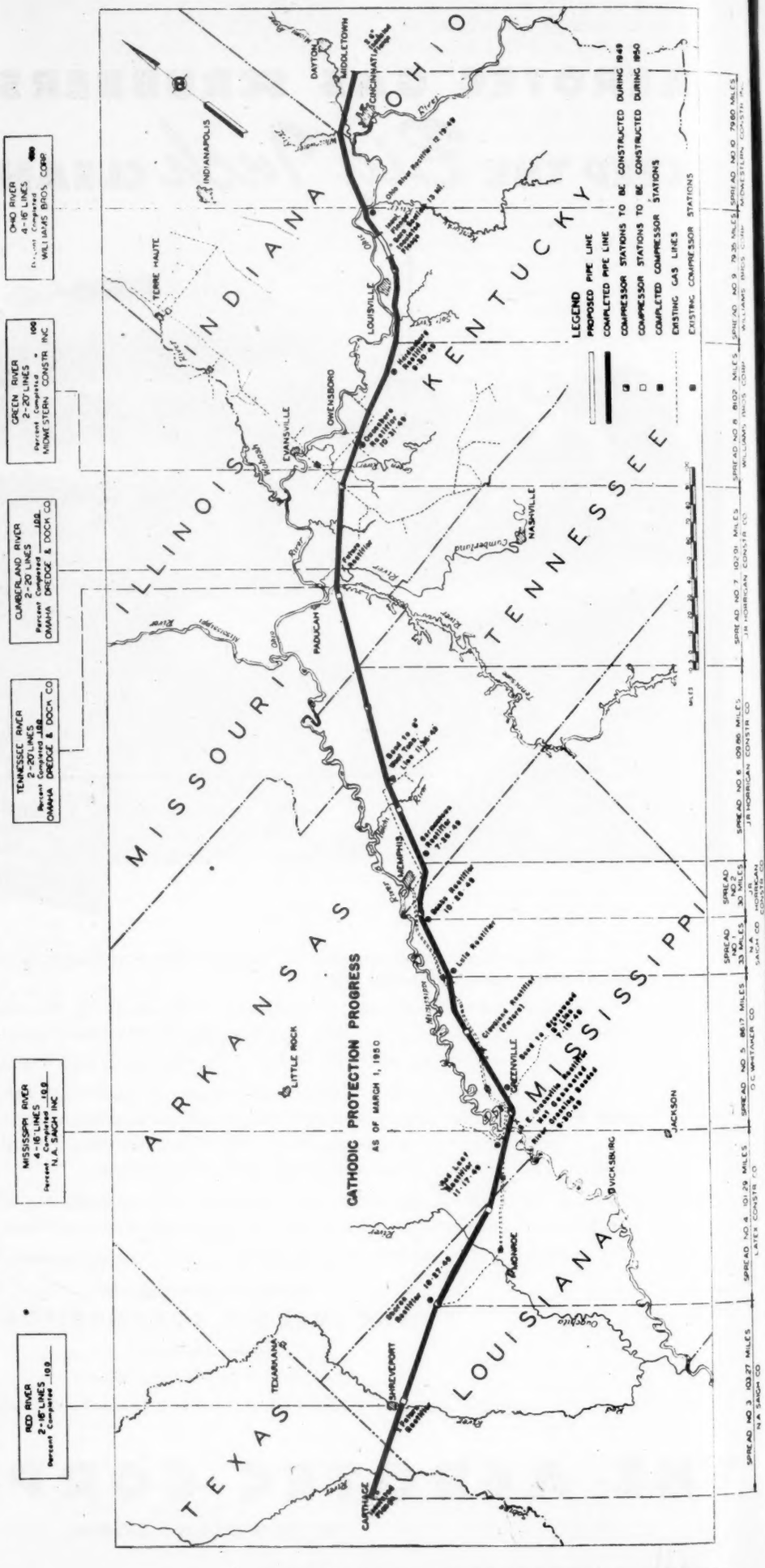
Where the line crossed other lines or structures, which were very few, care was taken to provide maximum practical separation and to insure that the coating and wrapping were in good shape.

Cathodic protection was provided by means of a small battery booster rectifier itself costing about $10 and served by 120-volt single phase ac from a rural electrification line at the very line of demarcation between Spread No. 1 and Spread No. 2 at Banks, Mississippi. The rectifier was connected to the south end of Spread No. 2 and Spread No. 1 automatically received cathodic protection when the tie-in was made at rectifier location.

The current generated by the rectifier was so small that the ground plate for the rectifier was set on the right-of-way.

Although the total amount of current indicated as needed for the 63-mile section was only 1.0 amp, the actual requirements were greater due to a mishap in installing at least a 40-ft length of 26-in. pipe without coating and wrapping during a tie-in in bad weather, in a low swampy low resistance location on Spread No. 1.

During the rush to get the line in operation by Christmas, 1948, this uncoated length of pipe was installed and record was lost of its location. The location of this bare pipe in the nearly perfectly coated and wrapped section of pipe line was later determined during the cathodic protection test work.



In order to measure the small cathodic protection currents on the 26-in. line drained by the Banks rectifier, a separate No. 8 test wire was provided at the rectifier connection and one placed 500 ft south and 500 ft north and the two latter brought and stapled to stub jobs set in the fields.

On January 24, 1949, the Banks rectifier was generating 2.57 amp at 5.6 volts of which 0.27 amp was being drained from the 30-mile north or Memphis end while 2.30 amp was being drained from the 33-mile south or Lula end. This great difference in current distribution was due mainly to the 40-ft length of 26-in. bare pipe inadvertently installed in the line south of the rectifier on Spread No. 1.

Potential tests indicated that the north end was receiving substantial protection except during some periods when the north end was greatly influenced by fluctuating stray currents out of the Memphis area by the very small cathodic current of 0.27 amp.

The south end with nine times the current, or 2.30 amp was not receiving full protection, in fact, this current collected mainly on the 40-ft bare section 2.5 miles south of the rectifier and beyond the bare section to the end at Lula, the line received only partial protection.

Due to these two complications, it was necessary to install another small rectifier at Lula compressing station and later another small rectifier station on Spread No. 6, just north of the Memphis end of Spread No. 2, in order to cope effectively with the stray currents in the Memphis area.

The exact distribution of current generated by the two additional rectifiers has not been determined, but since the total current is extremely small, the two components of the currents at the Lula and at the Memphis rectifiers must necessarily be small.

It might be added that the Lula rectifier added to the south end of Spread No. 1 is used presently to protect the north end of Spread No. 5 constructed in 1949 and the rectifier at Memphis known as the Germantown rectifier is also used to protect the south end of Spread No. 6 in addition to the protection afforded spreads Nos. 1 and 2, respectively.

Due to the great distances affected by the cathodic protection units, it is not necessary to install many test stations or test wires. The valves and blow-downs are spaced approximately every 10 miles and serve admirably as test stations.

Some additional test wires have been installed especially on the Memphis end of Spread No. 2 where the stray currents have been found. At all rectifiers, it is customary to install a test wire 500 ft each side of rectifier connection and rectifier test wire.

The 63-mile section known as spreads Nos. 1 and 2 were insulated by means of flanges from Lula compressing station and from a new Memphis measuring station. When the line was extended in 1949, spreads Nos. 1 and 2 were welded in solid to the adjoining spreads Nos. 5 and 6, respectively.

Although complete cathodic protection is assumed by many corrosion engineers to be obtained when a pipe line is lowered in potential to — 0.850 volt to a copper sulfate electrode, on the extremely well coated pipe lines under discussion, a potential of minus 1,000 volt to a copper sulfate electrode is usually striven for and also usually obtained even at remote points on the pipe line many miles from a rectifier.

Carthage to Middletown

To better visualize the pipe line in question, the reader is referred to the map accompanying this paper.

Spreads No. 1 and No. 2, between Lula, Mississippi, compressing station and Memphis, Tennessee, serve as a link in the 840-mile general line. Spread No. 1, between Carthage, Texas, and Sharon, Louisiana, compressing station was changed to 20-in. line.

Other deviations from strictly a 26-in. continuous line are the several river crossings where multiple crossings were installed. The number of pipes at each crossing and the contractor involved are shown on the map.

As can be seen from the map, the program for construction of the new pipe line was divided into ten spreads divided among several contractors. Spreads Nos. 1 and 2 were completed in 1948. Spread No. 3 between Carthage, Texas, and Sharon, Louisiana compressing station was delayed and several of the river crossings such as the Mississippi, the Tennessee, the Cumberland, the Green, and the Ohio were given out as separate jobs.

Seven of the spreads, Nos. 5 to 10 inclusive, each approximating 100 miles of 26-in. pipe were to be started at approximately the same time. Each spread in itself was a sizable pipe line job yet here in one organization eight such spreads to be moving simultaneously plus the several river crossing jobs and several large compressing stations. The work got underway on or about June 1, 1949.

It had been my plan to make early coating resistance tests on the first sections of each spread so that some idea could be gained of the quality of work performed by each contractor.

Fortunately the 63-mile "Pilot" section completed in 1948 had allowed many in the company to obtain first-hand knowledge of the construction of such a huge pipe line and this prior information on what and what not could be obtained in the way of good coatings and wrappings paved the way for obtaining similar results on the eight spreads constructed during 1949. Not too much instruction was necessary and all that was required was to keep up the good work.

During the middle of June, 1949, I visited spreads Nos. 6, 7, 8 and 9 from Memphis, Tennessee, to near Louisville, Kentucky, and made coating resistance tests on several sections of the above spreads, the result of which are given below:

Spread No. 6. Memphis, Tennessee, to Fulton, Kentucky:

1.5-mile section, U. S. Highway No. 72 to Wolf River. Hill soil. 934,500 ohms per sq ft.

8.0-mile section, Wolf River to Hatchie River. Hills and bottoms. 420,000 ohms per sq ft.

Spread No. 7. Fulton, Kentucky to Slaughters, Kentucky:

33-mile section, Fulton to near Tennessee River. Hills and bottoms. 1,-253,000 ohms per sq ft.

Spread No. 8, Slaughters, Kentucky, to Brandenburg, Kentucky, and *Spread No. 9, Brandenburg, Kentucky, to the Ohio River:*

18-mile section, part of Spread No. 8 and part of Spread No. 9, 29,000,-000 ohms per sq ft. This section through rugged rocky country.

From the above, initial coating resistance tests on four of the eight spreads under construction the results were especially favorable and prospects of cathodically protecing the huge pipe line with small amounts of electric current were promising.

On July 19, 1949, and thereabouts, Spread No. 5 extending from the Mississippi River at Greenville, Mississippi, to the Lula, Mississsippi compressing station was visited and a section approximately 35 miles in length from the Mississippi River to the Bogue Phalia was given complete cathodic protection by simply cross bonding to the 8-in. Greenwood, Mississippi, gas pipe line owned by the company and which was cathodically protected by means of a nearby rectifier. Current drained from the 35 miles of 26-in. line by the 8-in. line was originally 4.4 amp but after a few minutes this current had reduced itself to 3.2 amp due to polarizing effects of the current on the new line in the low, wet, and low resistance gumbo soils of this Mississippi Delta country.

Before cross bonding, the 8-in. line had a potential of minus 1.080 volt to a copper sulfate electrode and the 26-

in. line minus 0.700 volt. After cross bonding, the 8-in. measured minus 0.940 volt and the 26-in. minus 0.925 volt. Next day on the south side of the Bogue Phalia, or approximately 25 miles north of the cross bond, the 26-in. line measured minus 1.010 volt to a copper sulfate electrode, indicating still further polarizing of the newly protected 35-mile section overnight, since the day before at the cross bond potential was minus 0.925 volt.

Although a current test was not conducted next day on the cross bond, there is reason to believe that had such a measurement been made, the current would have been found to have been less than the minimum 3.2 amp found the day before, due to further polarization.

During the latter part of September and the first part of October, 1949, the writer again visited the northern spreads of the new 26-in. line. At the time of this visit 85 miles of line on spreads No. 8 and No. 9 were continuously welded into a solid section extending from U. S. Highway No. 71 south of Owensboro, Kentucky, to a point near the Shepherdsville Road southeast of Louisville, Kentucky.

Some fluctuating d-c potentials due to stray currents were observed on this section of pipe line so it was decided to install a rectifier on the section at once.

Accordingly on October 8, 1949, a temporary ground bed and rectifier station supplied by 120 volts single phase a-c was installed on the 26-in. north of Hardinburg, Kentucky.

The ground bed consisted of 6 pieces of 3-in. by 7-ft old steel pipes set vertically in the ground 27 ft north and parallel to the pipe line and spaced with 10 ft centers. The top of the pipes were allowed to protrude 1 ft above ground level where the wire connections were made.

The location is very hilly, with red top soil and limestone base. Postholes were dug for the ground bed pipes and blasting was necessary in the postholes to obtain proper depth.

The rectifier installation produced a current of 1.2 amp at 22.5 volts indicating a resistance of 18.75 ohms, most of which was in the ground plate.

This small current of 1.2 amp on 85 miles of coated and wrapped 26-in. pipe line produced a potential on the line of minus 1.580 to a copper sulfate in fairly but not sufficiently remote soil to be beyond the immediate effects of the ground plate.

Check tests made on the Owensboro end of this 85-mile section, or 33 miles south, indicated the small cathodic protection current of 1.2 amp applied at Hardinsburg was lowering the potential near Owensboro to between minus 1.075 and minus 1.175 volt, the variations due to stray current effects.

At Otter Creek State Park, Kentucky, southwest of Louisville and 27 miles northeast of Hardinsburg on the pipe line, potential was minus 1.000 volt to a copper sulfate electrode.

Even at the far northend at the Shepherdsville Road, southeast of Louisville, 52 miles from the Hardinsburg rectifier, later tests indicated that substantial protection was being afforded the line by the single small station but that stray currents, presumably originating in the Louisville area, were causing wild fluctuations that at times adversely affected the potentials of the 26-in. to the earth.

Since construction was proceeding on Spread No. 8 working southward and on Spread No. 9 working northward, the 85-mile section of these two spreads was gradually being enlarged. The small cathodic protection current of 1.2 amp applied to the 26-in. line at Hardinsburg was sufficient to take care of natural corrosion conditions on the 85-mile section but not sufficient to overcome the positive stray current swings. Adding miles of line plus some initial ageing of the coating and wrapping naturally taxed the 1.2 amp.

In order to augment the protection against these factors, a second small rectifier station was installed on the 26-in. line south of Owensboro on October 31, 1949. This new rectifier station was somewhat similar to the one at Hardinsburg in that the several pieces of junk steel ground bed were buried on the right-of-way parallel to the pipe line. The small rectifier set in a woden box on a pole, also on the right-of-way, was also served by a 120-volt, 2-wire, single-phase, power circuit.

This rectifier station drained 1.75 amp from the pipe line reducing the potential of the line at U. S. Highway No. 71, a mile or so away, down to a potential of minus 1.450 volt average to a copper sulphate electrode. It will be noticed that this rectifier circuit had a resistance of 5.56 ohms in contrast to 18.75 ohms at the Hardinsburg rectifier. This difference was due to the difference in soils at the two locations, the immediate ground plate having been buried in a low flat and badly drained location in contrast to the high, rocky and well drained site at Hardinsburg.

Since the above rectifier installation was made, spreads Nos. 8 and 9 have been completed and tied into adjacent spreads Nos. 7 and 10 and gas connections have been made to the Slaughters, Kentucky, and Jeffersontown, Kentucky, compressing stations. A very limited number of lateral gas connections have also been made. All such laterals are slated to be insulated from the main line by means of special insulated flanges and this insulation work is now generally in the process of installation.

During extremely bad weather in the fall months of 1949, the contractor working north of Louisville toward the Ohio River on Spread No. 9 requested that the coating and wrapping be eliminated on approximately 13 miles of the line in the rugged country north of LaGrange, Kentucky. This was finally and reluctantly allowed and in order to cope with the situation, a 26-in. insulated flange was installed in the line at both ends of this bare section. These two insulated flanges are the only joints other than welded in the entire line except for insulating flanges at Carthage, Texas, the southern end, at Lebanon, Ohio, the northern end, and all side connections.

The southernmost of these two insulated flanges becomes then the northernmost end of the cathodic protection on that portion of Spread No. 9, heretofore discussed.

Between the northernmost insulated joint on the bare section there are approximately 8 miles of coated and wrapped 26-in. line up to the header on the south side of the Ohio River, where Spread No. 9 ends.

This 8 miles of line connects to the four 16-in. at the Ohio River crossing and to the 26-in. line through southeast Indiana and southwest Ohio to the Texas Eastern plant at Lebanon, Ohio, known as Spread No. 10.

Plans have not been worked out for the protection of the 13-mile bare section. This bare section will be tested for electrical current requirements and will afford an excellent opportunity to make comparisons between bare and coated and wrapped lines.

The 8-mile section of Spread No. 9, the four 16-in. at the Ohio River crossing, and the southern part of Spread No. 10 began receiving cathodic protection on December 19, 1949, when a small rectifier station was installed on the south side of the Ohio River. This station was generating approximately 1.0 amp at 24.0 volts d-c. and while this current does not fully protect all of Spread No. 10, it is effectively protecting the valuable four 16-in. lines at the Ohio River crossing and all the 8 miles of Spread No. 9 as far south as the insulated flange separating the coated and wrapped pipe from the bare pipe.

This section, especially the northern end in Ohio, is slated for early

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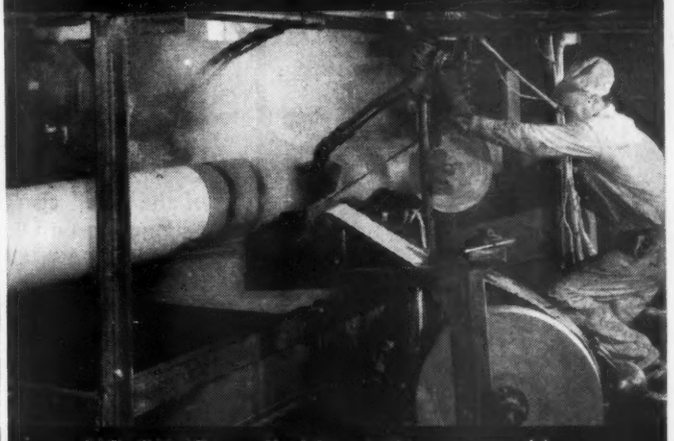

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Tests were made on a portion of Spread No. 10 in southeast Indiana and north of the Ohio River and also on the four 16-in. lines of the Ohio River crossing prior to the actual installation of the rectifier on the south bank.

On October 4, 1949, a test was conducted on the 26-in. line near Bear Branch, Indiana, the section under test extending 22 miles north of the Ohio River in southeastern Indiana and including also the four 16-in. Ohio River lines, each measuring approximately a mile long. The 26-in. line had not been constructed at that date on the south of the Ohio River.

This test made near the north end of the section indicated that 0.9 amp changed the potential of the line from minus 0.700 to minus 1.000 volt to a copper sulphate electrode but it was suspected that a considerable portion of the small current of 0.9 amp was originating on Ohio River crossing.

Accordingly, a test was made near the north side header at the Ohio River crossing on October 6, 1949, and it required 3.1 amp to lower the line from minus 0.700 to minus 1.025 volt to a cooper sulphate electrode, which indicated heavier grounding of the line at the river as had been expected.

Further testing indicated that three-fourths of the current drained during the present test was originating from the four 16-in. river lines and only one-fourth from the 22 miles of 26-in.

Later it was found that the valves on the river lines had not been hot coated up to the time of the test. These were subsequently hot coated, resulting in lower current requirements for the four river lines and the line in general in this vicinity as reflected by the obtaining of excellent protection with 1.0 amp supplied by the small rectifier later installed on the south side of the Ohio River.

Let us now work our way southward on this huge pipe line.

A rectifier is needed and will be installed shortly in the general vicinity of the Tennessee and Cumberland River crossings not far from Paducah, Kentucky. Early preliminary tests plus some made later, including the Tennessee River crossing but not the Cumberland River crossing, indicated high resistance coatings and no difficulties are expected in providing complete cathodic protection for the line and river crossings in question.

Farther south on Spread No. 6 in West Tennessee, halfway between the Mississippi and the Kentucky borders, the 26-in. line crosses the 8-in. West Tennessee gas pipe line owned by the company. This 8-in. line was already cathodically protected by two small rectifiers so a cross bond was provided between the 26-in. and the 8-in. lines just east of Ripley, Tennessee, on November 25, 1949.

I have not personally checked this bond nor the line in the vicinity in detail but reports supplied me indicated the 26-in. line was receiving substantial cathodic protection for many miles on both sides the bond with little slackening of protection on the 8-in.

Again farther south on Spread No. 6 in West Tennessee, we come to the Germantown rectifier. This rectifier was installed on July 26, 1949, just about a mile north of the start of Spread No. 6 or a mile north of the north end of Spread No. 2, which was constructed in 1948. The initial values of current and voltage generated by this rectifier on the above date were 1.3 amp at 5.9 volts dc.

This rectifier helps protect the north end of the 1948 Spread No. 1 from both soil corrosion and the stray currents encountered in the Memphis, Tennessee, area and also protects Spread No. 6 in some bad bottom lands of the Wolf, the Hatchie, and other rivers northeast of Memphis.

The next stop is at Lula, Mississippi, compressing station on the south end of older Spread No. 1 constructed in 1948. A rectifier was installed at Lula to augment the protection on Spread No. 1 needed on account of the bare length of pipe on Spread No. 1.

When Spread No. 5 from the Mississippi River to Lula was tied-in at Lula to Spread No. 1, the north end of Spread No. 5 automatically received cathodic protection from the existing rectifier. Here again some check measurements and refinements are planned for the near future but fragmentary tests here and there on the line in the vicinity indicate excellent protection is being obtained.

On Spread No. 5 just west of Cleveland, Mississippi, the 26-in. line undercrosses the two older 18-in. main lines of the company, formerly the main lines of Memphis Natural Gas Company. Both these latter lines are cathodically protected and wiring facilities have been provided at the crossing to cross bond all three lines if occasion arises. A rectifier station is planned for this location but some obstcales in obtaining right-of-way have been encountered and the matter is still pending.

On the south end of Spread No. 5 between the Mississippi River and the bond installed to the 8-in. Greenwood line, previously mentioned, the new 26-in. line is provided with a bond

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wire to a rectifier now serving the two older 18-in. lines of old Memphis Natural Gas Company but to date this bond wire has not been needed and is not connected.

Situations in this stretch affecting the cathodic protection picture are the Texas Gas Transmission Corporation's new compressing station, which presently is not cathodically protected, the older and highly cathodically protected compressing station of Tennessee Gas Transmission Corporation, the crossing of the new 26-in. line and the cathodically protected 24, 26, and 30-in. lines of Tennessee Gas, the two nearby cathodically protected 18-lines of Texas Gas including a ground bed and rectifier station serving same, the crossing of the 26-in. line and the cathodically protected 8-in. Greenwood line, and the 10-in. line between the new compressing station and the 8-in. Greenwood line, which parallels the new 26-in. line on which cathodic protection is to be applied. In addition, the 26-in. line ties into the four 16-in. Mississippi River lines for the 26-in. line and parallels at not too great distance eight other cathodically protected Mississippi River crossings.

From the above it can be seen that there are numerous underground metallic pipe lines and grounded metallic plant structures in the vicinity, most of which are cathodically protected involving direct currents flowing through the earth as well as on the structures. Cathodic protection or other grounded direct currents can cause damage to underground metallic structures if not properly controlled so in an area like the one in discussion from the Mississippi River to the Greenwood 8-in. line, the relationship of the various grounded electrical factors must be recognized, understood, and properly controlled in order to avert damage to one structure or the other.

Fortunately, close cooperation exists between the two large pipe line systems involved and the problems encountered in the past have always been worked out satisfactorily to everyone concerned.

Let us now consider the four 16-in. lines crossing the Mississippi River. The Mississippi River at the crossing is approximately 2500 ft wide from edge to edge during low water and from header - to - header behind the levees the distance is approximately two miles. The Mississippi River at the crossing is probably as swift if not swifter than at any other location in its course.

The plans and specifications called for cleaning, priming, and hot coating both the pipe and the river weights, the headers, valves, blow-down risers, and any metal touching the line. The lines were laid from barges with all-welded joints.

Upon completion this enormous submarine crossing was tied into the 26-in. line on both the Arkansas side and on the Mississippi side of the Great River and the coating job was so good that cathodic protection was automatically supplied by the cathodic protection on the land lines supplied on the Mississippi side by the bond to the 8-in. Greenwood line, which is approximately 10 miles from the east side header, and by a connection to the Red Leaf, Arkansas, rectifier, which cathodically protects the two older 18-in. lines and which is approximately 2.5 miles from the west header.

Reports reaching me after the tie-ins were made indicated the four 16-in. river lines were receiving full protection from these two sources of cathodic protection current but to date no detailed tests have been conducted to determine just how much amperage is being consumed by these lines.

The total must necessarily be small otherwise the two distant cathodic stations would not have been able to shoulder the added load and at the same time provide adequate cathodic potentials on the river crossings.

Judging from the results on other nearby river crossings, the current requirements probably run about an ampere or less for each of the four 16-in. lines, each of which is approximately 2.5 miles in length.

Proceeding now to the west or Arkansas side of the Mississippi, we come to Spread No. 4, which extends 101.29 miles to the Sharon, Louisiana, compressing station.

The 26-in. line crosses the 24, 26, and 30-in. lines of Tennessee Gas Transmission Corporation not far from the west bank header, but no interconnections were actually made here because interconnections between the two older 18-in. lines of Texas and Tennessee Gas exist close by.

At the crossing of the new 26-in. and the two 18-in. lines, approximately two miles from the river, cross bonds were provided between all three lines and several hundred feet west a connection was provided direct to the negative wire of the Red Leaf, Arkansas, rectifier, which cathodically protected the two 18-in. lines and which also helped protect Tennessee lines.

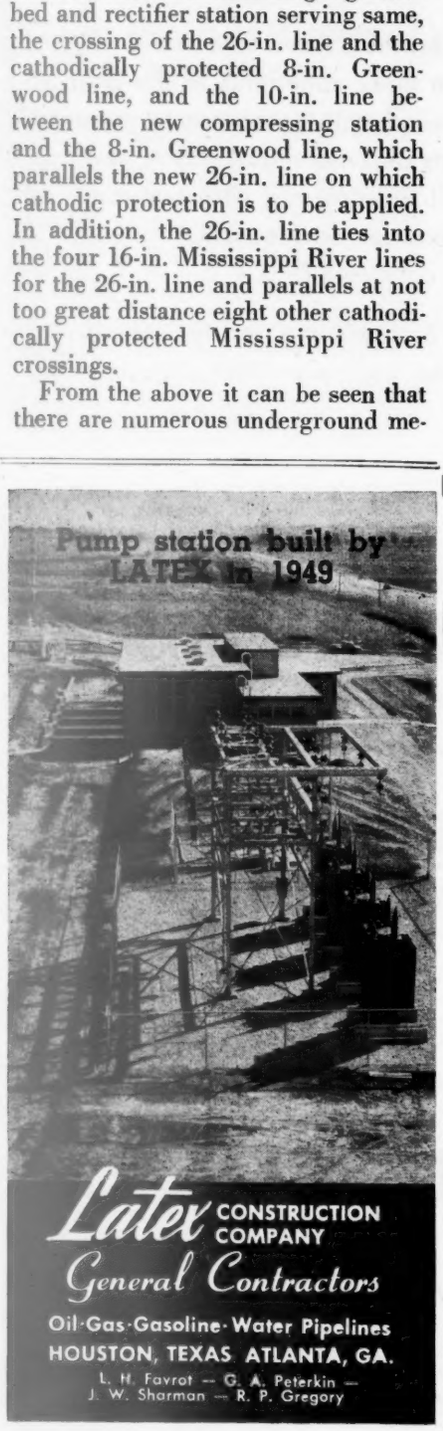
This rectifier connection then provided cathodic protection for the 26-in. line, for the Mississippi River crossings, and for a considerable mileage on the 26-in. line towards Sharon compressing station, providing protection to the 26-in. line through the low lying and corrosive swamp and cotton plantation country with its many bayou crossings.

The protection afforded by Red Leaf Rectifier featheredges out as the line approaches Sharon and at Sharon the protection becomes zero, for the line was connected in solid to the compression station and up to latest reports had not been provided with the planned insulating flanges. Fortunately the soil conditions on the hilly Sharon end are not considered as severe as in the low lying swamp end near the Mississippi River.

At Sharon, a small rectifier is already installed and operating on another pipe line, and as soon as the insulating fiange is installed in the 26-in. line this line will be connected and the west end of Spread No. 4 will receive protection.

The last spread in question is No. 3, which extends from the far south end of the whole line at Carthage, Texas, to the Sharon, Louisiana, compressing station.

This section of the big line was reduced to a 20-in. line and construction on it did not begin as early as on the other spreads. This line runs through the red, hilly country of East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Latex CONSTRUCTION COMPANY
General Contractors
Oil-Gas-Gasoline-Water Pipelines
HOUSTON, TEXAS ATLANTA, GA.
L. H. Favrot — G. A. Peterkin —
J. W. Sharman — R. P. Gregory

Texas and northwest Louisiana and involves a crossing at Red River, which often goes on a rampage.

Spread No. 3 is to be insulated from the incoming supply stations on the Carthage end and also at Sharon compressing station. Cathodic protection will be provided at Sharon and probably at another point or two to be determined.

Spread No. 3 crosses many important foreign pipe lines and these lines must be taken into consideration in the protective plan.

Cathodic protection is not complete on the new 26-20-in. line of Texas Gas Transmission Corporation but probably 75 per cent of the line is wholly protected inculding all the locations considered as possibly corrosive. By this summer, the line from end to end should be receiving full cathodic protection with the exception of the 13 miles of bare line in Kentucky, on which some economic solution shall have to be worked out.

Miscellaneous

There were several items of construction that may be of interest. One was the use of metal Grip-Tite anchors to fasten the line in some wet boggy locations. These anchors are constructed of a galvanized steel plate, formed to fit the pipe, two long galvanized steel bolts, and a black iron or steel expanding anchor.

In order that this bare metal did not touch the steel pipe, layers of asbestos pipe line felt were used under the plate in some instances to prevent the plate and pipe forming a metal-to-metal contact. Cathodic protection, then, was not applied to these anchors. At other locations special insulated padding was used under these plates.

These anchors are particularly valuable during construction and for the first few years after the pipe has been backfilled when the backfill is soft and easily moved. I understand premanent life of these anchors is not an important factor and that they will serve their purpose long before complete deterioration is expected, if it ever occurs.

In the rocky country of Kentucky where a lot of blasting had been done, special precautions were used so that the coating would not be badly damaged by the bottom of the trench and by the backfill. In some cases loam soil was used in the bottom of the trenches and in the backfilling care was taken to exclude the larger rocks. Special bituminous padding was also used on the top of the pipe in some instances to prevent damage by rocky backfill.

The electrical generating equipment used so far on the 26-in. line has been rectifiers of various kinds, supplied by 120-volt single phase a-c electric power mostly from rural power lines but in two instances from compressing station electrical circuits.

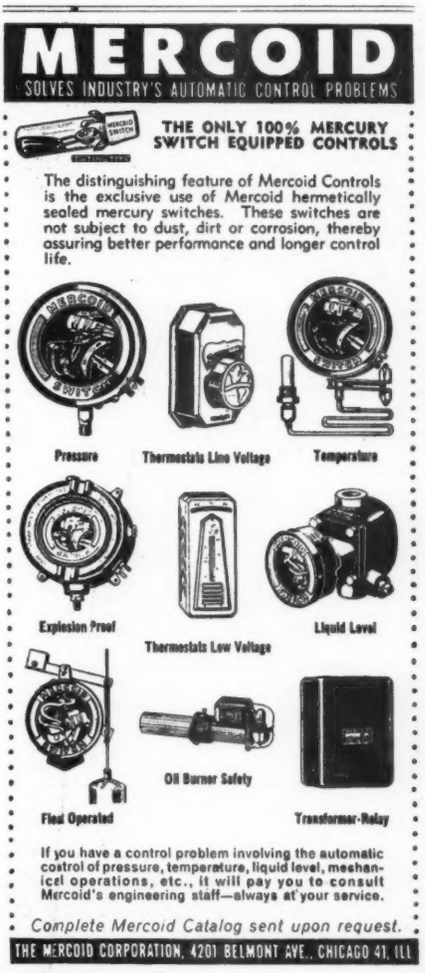
One difficulty encountered is the high resistance soil found at otherwise favorable rectifier locations. Fortunately the currents required have been small, which lightens the task of obtaining a good ground bed. In some instances it has been necessary to place two rectifiers in series in order to obtain a few amperes through the high resistance ground beds using the low voltage equipment on hand. It is hoped that eventually sufficient ground bed material may be buried at each site so that the very inexpensive and convenient size transformers can be used above at the various stations and not in a series combination.

There were so many things done during construction affecting the cleaning, coating, and wrapping of the line and eventually affecting the corrosion situation and cathodic protection that it is impossible to cover all that transpired in this paper.

My work involved recommendations during the planning stage plus some field inspections and surveys during construction plus follow-up work after the major job of construction was completed. Those within the company organization who were entrusted with the construction did such a splendid job of seeing whatever was specified was accomplished that the task of applying cathodic protection to this huge system was made relatively easy. Aubrey L. Roberts, now general superintendent of the entire company, had direct charge of the construction and he and all his assistants deserve congratulations and also thanks for excellent cooperation encountered at every turn.

The same applies to the several contractors on the various spreads who despite the large diameter, the heavy equipment, and the rugged country, all seem to have conspired to do a good job, especially from my point of view, on the coating and wrapping.

Thanks also to the top management for giving me the opportunity to participate in the design, construction, and operation of this great pipe line, to Herbert L. Stowers, chief engineer of the company, and to Fred D. Stull, superintendent of communications and corrosion, who personally accompanied me on all visits to the property and participated in the work in connection with the cathodic protection program. * * *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Torsional Vibration*

All Possible Arrangements in Connection With an Installation of Heavy Engines Should Be Investigated and Most Desirable Chosen—How This Can Be Done.

T. S. LLEWELLYN†

THE operation of diesel engines is often influenced by so-called critical speeds. These speeds are characterized by a change in engine performance during which there may be violent shaking of exterior parts, chattering of gears, unstable speed, and definite vibration of the whole engine or driven machine. This phenomenon is not confined to diesel engines but is common to all internal-combustion engines and may be found in machines of all types. Critical speeds in diesel engines are caused by torsional vibration of the crankshaft. They may occur at one or several points in the operating speed range.

Crankshafts can vibrate transversely, axially, or circumferentially. The latter is torsional vibration and it is most important because of its common occurrence. During this vibration the shaft swings forward and backward in the plane of its rotation. The vibration is often severe enough to break the shaft by torsional fatigue or to cause failure of gears, chains, auxiliary equipment, etc. The condition arises because fluctuating torques twist elastic shafting; since this condition is inherent in engines, the matter should be considered in connection with every installation of heavy machinery.

To visualize how a shaft vibrates torsionally, consider a straight steel shaft with a flywheel at each end. If this shaft is twisted by turning one wheel as the other is held firm and then both are suddenly released, the resiliency of the steel shaft will cause the wheels to rock on their axes in relatively opposite directions. This is torsional vibration, and it will continue until the energy of the original twist is dissipated by friction. The rapidity or frequency of the rocking motion will be constant regardless of the degree of original twist as this is governed solely by the shaft stiffness and the inertia of the flywheels. This constant frequency is called the natural frequency of the vibrating system. If additional energy can be imparted to the vibrating flywheels, in phase with their motion, the amplitude of the vibration can be sustained or even increased. This principle of increasing a vibratory motion is familiar to children using playground swings.

As the shaft is twisted and the flywheels move in relatively opposite directions, there is, obviously, some point along the shaft at which the motion changes direction and, therefore, remains stationary. This point is called the node. A shaft with two flywheels can have only one node; one with three flywheels can have two nodes; the number of possible nodes is only one less than the number of masses attached to the shaft. Vibrating systems with several masses can move so as to have one or more nodes but the natural frequency in each case is different. The one noded vibration has the lowest natural frequency. For each successive node the difference in frequency is progressively smaller.

The calculations for the vibration characteristics of actual engines is based on the flywheel and shaft analogy. The running gear of the engine and driven machine is represented by a simplified mass-elastic system. Because of the complicated shape of an engine crankshaft, the simplified system is based on empirical formulae.

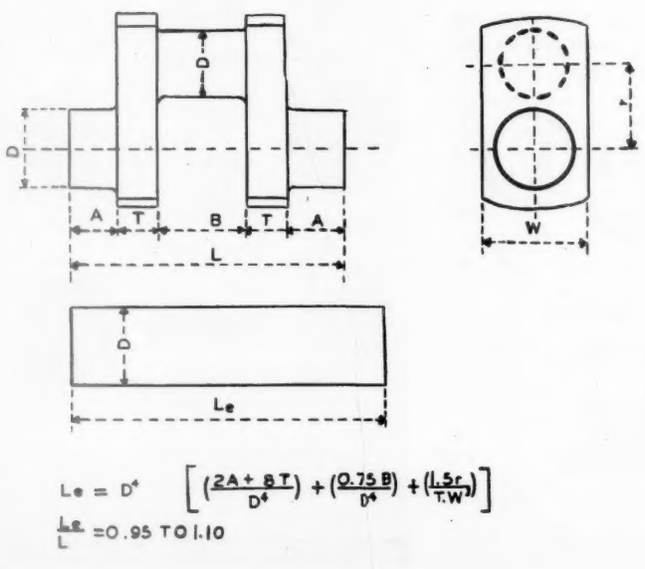
Fig. 1 shows a typical crank section of a large engine shaft for which the stiffness is to be found. The first step is to find its equivalent length, L_e. The formula given is that derived by Carter and will give reasonable results. From the equivalent length the stiffness of the section is conveniently figured by the ordinary rules for torsional deflection. That is,

$$C = \frac{Ip.\ G.\ \phi}{L_e}$$

Where:
C = stiffness in lb—in.
Ip. = polar moment of inertia = 0.098 D^4,
G = modulus of rigidity = 11.8 $\times 10^6$,
ϕ = angular deflection,
L_e = length in inches.

*Presented before The Pipe Liners Club of Tulsa, under title, "An Introduction to the Problem of Torsional Vibration."
†Service Pipe Line Company.

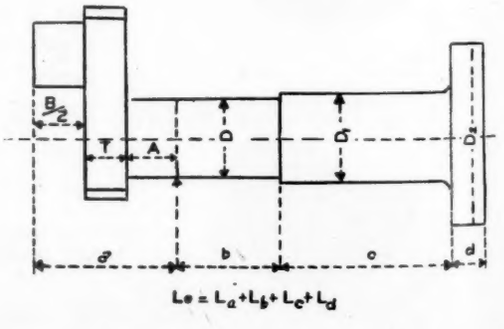
FIG. 1



$$L_e = D^4 \left[\left(\frac{2A + BT}{D^4}\right) + \left(\frac{0.75\,B}{D^4}\right) + \left(\frac{1.5r}{T.W}\right) \right]$$

$$\frac{L_e}{L} = 0.95 \text{ TO } 1.10$$

FIG. 2



$$L_e = L_a + L_b + L_c + L_d$$

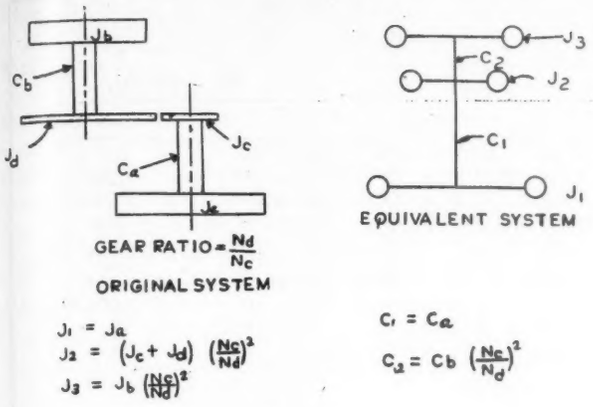


FIG. 3

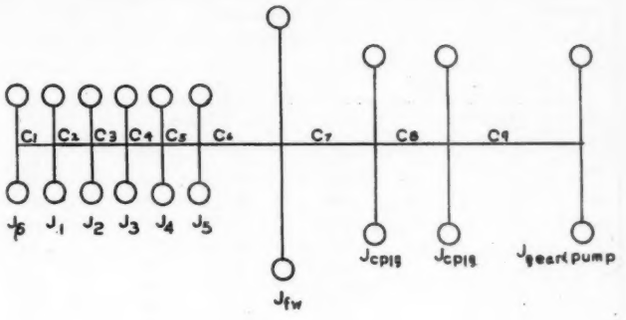


FIG. 4

The stiffness, C, is generally found for a deflection of one radian so that for a steel shaft the formula reduces to:

$$C = \frac{1.158 \times D^4 \times 10^6}{L}$$

$$= \text{lb-in./radian}$$

When a shaft ends with a flange, the shaft is considered to extend halfway through the flange. For pressed on hubs, etc., the shaft is assumed to extend into the hub about a third of the shaft diameter. Where the shaft has several different diameters the equivalent length is found for the base diameter and the stiffness figured accordingly. Fig. 2 represents a shaft section between the end cylinder and flywheel flange of an engine and demonstrates the above rules. Section "a" has half the equivalent length of the section shown in Fig. 1, Section "b" can be considered as having an equivalent length equal to the true length, as the change in section is small. The diameter D, of Section "c" extends into the flange a distance equal to d/2. The equivalent length of Section "c" based on diameter D, is given as L_c or:

$$L_c = \left(\left(c + \frac{a}{2}\right)\left(\frac{D^4}{D_1^4}\right)\right)$$

L_d for Section "d" is then:

$$\frac{d}{2}\left(\frac{D^4}{D_2^4}\right)$$

where D_2 is the bolt circle diameter of the flange.

The stiffness values for flexible couplings are provided by the manufacturers from physical test data.

When the driven machine operates through gears, it is convenient to convert all factors to an equivalent value at engine speed. Fig. 3 shows this diagrammatically. The equivalent stiffness and inertia factors are obtained by multiplying by the square of the gear ratio.

In the simplified mass-elastic system the equivalent inertia is found for each revolving mass of any consequence. The moments of inertia for revolving masses are ordinarily expressed in units of lb-in. sec.^{2}. Therefore J, the moment of inertia, is equal to WK^2/g where g is the acceleration factor of gravity and equal to 386 in./sec^2; k^2 is the radius of gyration of the weight, W. The expression Wk^2 or WR^2 is defined as the "flywheel effect" of the mass.

It is beyond the scope of this paper to go into detail for figuring the J factors for crank sections, flywheels, etc. In most cases the calculation can be made with the help of standard engineering handbooks. Of course, dimensions of the shaft and weights of rod, crank bearing and piston must be known. The purely rotating part of the crank-piston assembly offers no real difficulty; however, the piston and upper end of the rod reciprocate and during part of the crank revolution they are stationary. Stated briefly, the problem is handled by assuming that 0.4 of the rod weight is reciprocating and thus it is added to the weight of the piston. Half of the reciprocating weight is then considered to have a rotating motion. The equivalent J for the reciprocating weight at crank radius, r, is then, taken as:

$$J_{rec.} = \frac{W.r^2.}{2g}$$

Jrec. is added to the J for the rotating elements.

The J's for flywheels, hubs, gears,

FIG. 5. HOZLER TABULATION

N. F. = 1190 Vib. per min. $\quad W = \frac{1190 \times 2\,n}{60} = 124.5$ Rad. per sec. $\quad W^2 = 15{,}500$ Rad.^{2}/sec^2

Mass	J lb-in sec^2	Torque per unit deflection lb-in/rad.	Deflection ϕ radians	Torque in plane of mass J. W^2 ϕ	Total Torque lb-in	Stiffness C lb-in/rad.	Change in deflection $\Delta\phi$
J_b	360	5.59 x 10^6	1.000	5.59 x 10^6	5.59 x 10^6	354 x 10^6	.01578
J_1	500	7.75 x 10^6	.9842	7.63 x 10^6	13.22 x 10^6	290 x 10^6	.0456
J_2	500	.75 x 10^6	.9386	7.26 x 10^6	20.48 x 10^6	290 x 10^6	.0706
J_3	500	7.75 x 10^6	.8680	6.72 x 10^6	27.2 x 10^6	290 x 10^6	.0938
J_4	500	7.75 x 10^6	.7742	6.0 x 10^6	33.2 x 10^6	290 x 10^6	.1145
J_5	500	7.75 x 10^6	.6597	5.1 x 10^6	38.3 x 10^6	233 x 10^6	.1642
J_{FW}	39,400	611 x 10^6	.4955	303 x 10^6	341.3 x 10^6	170 x 10^6	2.004
J_{cplg}	750	11.6 x 10^6	— 1.5085	—17.4 x 10^6	323.9 x 10^6	540 x 10^6	.6175
J_{cplg}	653	10.2 x 10^6	— 2.126	21.7 x 10^6	302.2 x 10^6	22 x 10^6	13.72
J_{pump}	1,240	19.2 x 10^6	—15.846	304 x 10^6	—1.8		

Note: The negative residual torque of —1.8 indicates the assumed N. F. is slightly high. A positive residual torque for the 1 — node N. F. would indicate the assumed N. F. is too low.

FIG. 6

N. F. = 1,820 W = 190.6 W^2 = 36,300

Mass	J	Torque	ϕ	Torque x ϕ	Σ Torque	C	$\Delta\phi$
J_b	360	13.1 x 10^6	1.000	13.1 x 10^6	13.1 x 10^6	354 x 10^6	.037
J_1	500	18.15 x 10^6	.963	17.5 x 10^6	30.6 x 10^6	290 x 10^6	.1055
J_2	500	18.15 x 10^6	.8575	15.6 x 10^6	46.2 x 10^6	290 x 10^6	.1592
J_3	500	18.15 x 10^6	.6983	12.7 x 10^6	58.9 x 10^6	290 x 10^6	.203
J_4	500	18.15 x 10^6	.4953	9. x 10^6	67.9 x 10^6	290 x 10^6	.234
J_5	500	18.15 x 10^6	.2613	4.74 x 10^6	72.64 x 10^6	233 x 10^6	.312
J_{FW}	39,400	14.30 x 10^6	—.0507	—72.5 x 10^6	.14 x 10^6	170 x 10^6	.0008
J_{cplg}	750	27.2 x 10^6	—.0515	—1.4 x 10^6	—1.26 x 10^6	540 x 10^6	—.0023
J_{cplg}	650	23.6 x 10^6	—.0492	—1.16 x 10^6	—2.42 x 10^6	22 x 10^6	—.11
J_{pump}	1,240	45. x 10^6	.0608	2.72 x	.3 x 10^6		

Note: Positive residual torque indicates N. F. is too high.
Negative residual torque indicates N. F. is too low.

etc., are calculated by conventional means.

At this point it is assumed that the C and J values have been determined for a 5-cylinder, 4-cycle engine of 16¼-in. bore and 23-in. stroke, which is used to drive a horizontal triplex double acting plunger pump. The drive is through single reduction gears and has a flexible coupling between the flywheel and pump pinion shaft. The crank shaft has an auxiliary flywheel at its free end. Fig. 4 represents the system. The values of J and C are set down in a Holzer table as shown by Fig. 5. This is one of several methods for determining the natural frequency. It has the advantage of giving good results even when the various steps are figured by slide rule. Essentially, it is a trial and error method but it is not overly tedious even when several trials must be attempted. It has the added advantage of showing directly the relative angular deflection at each mass and the position of the node or nodes. The theory behind the tabulation is rather involved but it is based on the fact that when a system vibrates the torque required to produce the vibration of the first mass J_1 is equal to J_1 "w^2" sin $wt\phi$ or mass times acceleration. In this case, w is the phase velocity in radians/sec of the torsional oscillation and not the angular velocity; for the first trial its value is assumed. ϕ is the angle of twist. The torque required for the vibration of J_1 can come only from the right of this mass. As the stiffness, C_1 of the shaft from J_1 to J_2 is known, the deflection beween these two masses will be $J_1w^2\sin wt/C_1$ or J_1w^2/C_1 for the maximum deflection of one radian. The amplitude of the vibration at J_1 is assumed as one radian. The amplitude at J_2 will consequently be $1 - \frac{J_1w^2}{C_1}$ and this requires a torque equal to

$$J_2w^2 \left(1 - \frac{J_1w^2}{C_1}\right)$$

The total torque acting at J_2 will include the torque at J_1. The deflection between J_2 and J_3 and the torque at J_3 are worked out in a similar manner and by successive steps, as shown in the tabulation, the torque can be found at each mass and at the end mass, J_n. If this final residual torque is zero or nearly so the phase velocity w has been assumed correctly for the natural frequency of vibration as this indicates a free vibration requiring no torque to sustain it. A positive or negative residual torque indicates to what extent the first assumption of w is incorrect. Since w can be considered as the constant angular velocity in radians/sec of a rotating vector, which when represented as a simple harmonic motion, reproduces the same angular motion as that of the vibratory motion in the shaft, the natural frequency will be equal to $\frac{w \times 60}{2\pi}$.

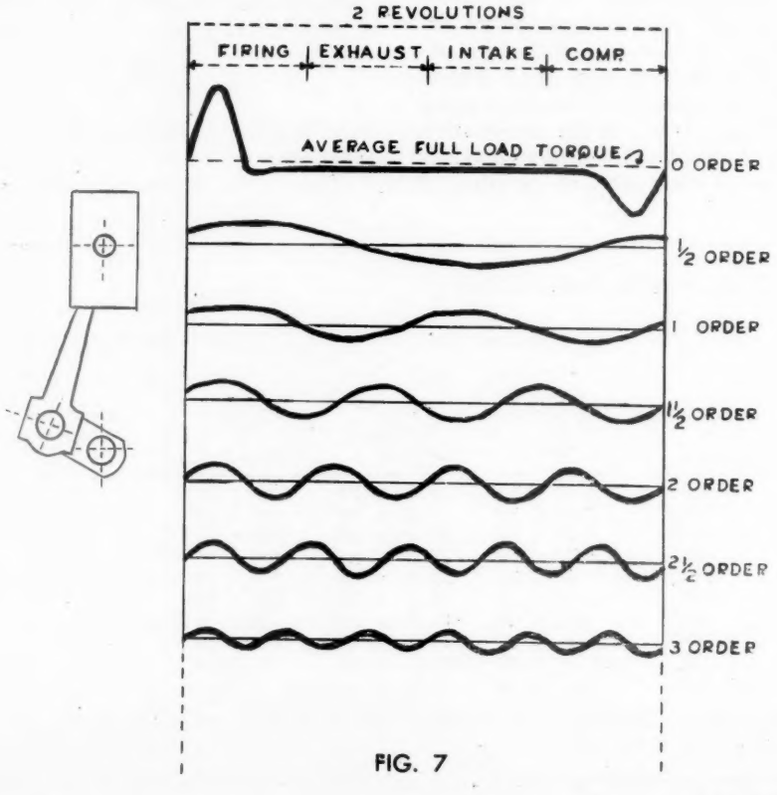


FIG. 7

The tabulation in Fig. 5 has been made for the one node vibration. That this is the one node vibration is shown by the value of the units in the column for deflection. These show the masses change direction of oscillation only between the flywheel and coupling.

In Fig. 6 a similar tabulation is made for the two noded vibration. In this case, the direction of oscillation is changed between No. 5 cylinder and the flywheel and again in the pinion shaft between the coupling and gear of the pump.

The natural frequency for the one node vibration is found to be 1190 vibrations per minute and for the two noded frequency 1820 vibrations per minute. The maximum vibratory torque for 1 radian amplitude at the first

mass, recorded in the tabulation of Fig. 5, is 343 × 10^6 lb-in., and in Fig. 6 it is 72.63 × 10^6 lb-in. In each case the shaft diameter is 9⅞ in. at the node where the maximum torque is acting. The stress in the shaft at the nodes is now calculated for a deflection of one degree at the free end of the shaft by using the torque for one radian deflection and making allowance for it in a standard torsional stress formula, that is:

$$\text{Stress} = \frac{16T}{\pi D^3} = \frac{16 \times \text{Tmax}}{57.3 \times \pi \times D^3} = \frac{\text{Tmax}}{11.25 \times D^3}$$

For the one node vibration the stress is 31,500 psi per degree at the free end of the shaft. For the 2 node vibration the stress is 6700 psi.

Methods have been worked out to predict the actual deflection at the free end of the shaft for various orders of vibration. From these values for deflection the stress is calculated from the foregoing; however, regardless of these calculations, it is always better to analyze the system and try to introduce elements that will change the frequency so that harmful major critical speeds are safely outside the operating range. This often can be done by changing the type of flexible coupling; or within rather broad limits the WR^2 of the flywheel may be varied; sometimes extension shafting can be altered; any change in mass not near a node will be effective. When these methods will not correct conditions the use of a vibration damper is advisable. This device can generally be adapted to the free end of the shaft and it is extremely effective for absorbing vibrations.

For the example shown in Figs. 5 and 6 the engine was torsiographed and a severe two noded vibration was recorded at 244 rpm. The torsiograph is an instrument that gives a graphical record of the angular deflection of the shaft and the frequency of the vibration. This graph gives a positive figure for determining stress as well as type of vibration. For this engine, the deflection was found to be 1 degree at 244 rpm and, as the frequency was shown to be that for the two noded vibration, the stress was 6700 psi. The shaft in this engine broke in the No. 5 crankpin and in order to reduce the vibratory stress a viscous damper was subsequently installed in place of the auxiliary flywheel and the stress reduced to 1950 psi.

The question of what constitutes a safe stress can not be readily answered without a consideration of the actual shape of the shaft. For ordinary cranks, as illustrated in Fig. 1, stresses greater than 3000 psi should be avoided. For straight shafts a stress of 10,000 psi is safe.

For the average installation only the one and two noded vibrations need to be investigated as the harmful criticals for other nodes are usually beyond the operating range. The reader may recall that mention was made of critical speeds being encountered at more than one speed. This statement will now be investigated.

Fig. 7 shows on the left the masses of the running gear of one cylinder. The pressure acting on the piston is transmitted to the crank in the form of tangential torque. This torque is far from uniform and it is this lack of uniformity that sets the shaft to twisting and thereby vibrating. It is seen that the average torque is only a fraction of the torque during the firing cycle and at the 4 dead center positions of the 2 revolutions of the complete cycle the torque is zero. The only effect of load is to change the torque during the firing stroke. Actually, with no load the torque during the firing stroke will equal that during the compression stroke so that even without load there is a fluctuating torque.

The torque curve can be broken down into a multitude of harmonic curves, the total sum of which equals

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the original torque curve. These harmonics are designated as orders as shown to the right in Fig. 7. The first of these forces has one half period per engine revolution, the second has 1 period per revolution and so on to infinity. They are called the harmonics of the ½, 1, 1½, etc. because they show as many full sine waves per revolution. The only useful harmonic is the 0 order or average torque. It produces work. The others only produce vibrations.

As there in an infinite number of harmonics that produce synchronous motions in the crankshaft, any one of them can force a vibration, which is produced independently of the other harmonics. When the forced harmonic vibration happens to correspond to the natural frequency, the free vibration is amplified and except for damping, this resonant condition would destroy the shaft.

The harmonics are classified as major and minor. In 4-cycle engines the major harmonics are those corresponding to whole number multiples of the firing impulses per crankshaft revolution. In the 5-cylinder engine cited, these would be the 2½, 5, 7½, etc. In a 6-cylinder engine they would be the 3, 6, 9, 12, etc., but, in this case, a minor harmonic such as the 7½ can be troublesome with certain firing orders. The question of firing orders will not be elaborated upon herein.

Returning to the natural frequencies of 1190 and 1820 for the 5-cylinder engine analyzed in Figs. 5 and 6, consider first the one node vibration. The operating range of the engine was between 175 and 277 rpm and therefore only one critical speed can be expected to be encountered within the operating range. This is the 5th order vibration caused by the 5th harmonic at 1190/5 or 238 rpm. From the high stress of 31,500 psi calculated for 1 degree deflection of the free end of the shaft, one might expect a severe disturbance from even a modest reaction of this harmonic. However, the calculated stress was less than 2000 psi and the vibration was not found with the torsiograph because its position was very close to the 7½ order, two noded vibration which was of greater amplitude.

The two noded vibration at 1820 cycles per minute gives the following critical speeds for major harmonics:

Order	*RPM*
5	364
7½	242
10	182

The 5th is beyond the operating range. The 7½ was calculated as causing a stress of as high as 7350 psi. The torsiograph showed this to be 6700 psi. The 10th order at 182 was not of much importance.

In connection with the 7½ order, the actual calculated stress, when using accepted constants based on experience, was found to lie between 4000 and 7350 psi. This is a rather wide spread and so indefinite that the method for this calculation has been purposely omitted here. After reviewing a representative number of calculations made by various authorities, the writer has acquired a rather pessimistic outlook for stress forecasts when the frequency calculation shows a major critical speed is present within the running range. Major criticals would exclude anything above the (N cylinder × 2) order. Rather than to put too much faith in a numerical calculation of stress where a major order is concerned, the writer advises that all possible arrangements of a proposed system be investigated and the most desirable chosen. If major criticals are still present within the speed range, the system should be torsiographed after installation and dangerous critical speeds located. Severe vibrations occupy broad ranges in operating speed and with the torsiograph the limits can be defined. In the final analysis the torsiograph ends all doubts.

* * *

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Competitive Position of Natural Gas versus Coal, Fuel Oil, Manufactured Gas, and Atomic Energy*

FRANK H. DOTTERWEICH†

THE competitive status of natural gas as one of the principal sources of energy supply in the United States may be better understood and analyzed when it is compared first with primary fuels like coal and fuel oil; secondly, with manufactured gas; and finally, with atomic energy. Such a study, showing comparative prices and price trends, should include consumer statistics, reserves, related economics, and developments that may be expected when technological accomplishments are evaluated. After the foregoing information has been set forth and commented on, it will be seen that natural gas as a fuel and source of energy commands an ever-increasing position of importance in the fuel picture of the nation.

Sources of Energy Supply

At the turn of the century the most important energy sources of the nation were coal (anthracite, bituminous, and lignite), natural gas, petroleum, and water power.

The Bureau of Mines has converted these various energy sources into British thermal units, and these various sources of energy supply from 1900 through 1947 are available. It will be noted that while natural gas utilization has risen from 3.2 per cent of the total in 1900 to 13.3 per cent in 1947, the total energy supply has increased more than four times so that natural gas utilization has increased about 18 times in the period 1900 to 1947. During this same period the use of coal in all its forms about doubled. The contribution of petroleum to this supply has increased more than thirty-fold in this period. It will be noted that in the more recent period of 1940-1947, however, usage of petroleum has remained at 32.9 per cent without further increase, while the pertentage contribution of natural gas has continued its increase from 11.2 per cent to 13.3 per cent in 1947.

Annual estimates of the nation's reserves of coal, petroleum, and natural gas are available. When reviewed, it will be seen that because of the magnitude of the coal reserves in relation to the annual rate of consumption, the year-to-year coal reserve statistics do not change to any great extent. Although discoveries exceed production, petroleum and natural gas reserves of about 23.3 billion barrels and 173.9 trillion cubic feet, respectively, do not approach the magnitude of coal reserves. The substantial continuous increase in gas reserves indicates that upon reaching a maximum position it can continue as a highly competitive fuel in the national picture over a long period of years.

Comparative Prices of Fundamental Fuels

The relative prices of the fundamental fuels, natural gas, coal, and fuel oil, are better seen when reduced to a common denominator and reported in terms of cents per million Btu. In addition, such a comparison should include both the residential and industrial levels. In the comparison on the residential or domestic level, burning efficiencies should be taken into consideration. In this study the bases of 84 per cent for coal and 92 per cent for fuel oil as compared to the efficiency of gas have been used. Also, this comparison on the domestic level is restricted to central househeating because it is at this level that these fuels are directly competitive.

Table 1 sets forth the percentage change in the prices of the fundamental fuels over a seven-year period, from 1940 to the beginning of the heating season of 1947-1948[1]. It will be noted that in the 23 cities cited in this study there have been very substantial increases in the price of coal and fuel oil in all cities. Natural gas prices have, with few exceptions, declined on the domestic level or remained the same.

Table 2 indicates that during the 1947-1948 heating season any relative advantages in the price of coal and oil for central househeating that may have existed during any prior time have changed so that during this period many cities had natural gas cheaper than fuel oil. When the advantages of natural gas from a standpoint of cleanliness, convenience, continuous service, etc., are taken into account, it appears that natural gas is now the more economical fuel for residential heating purposes in most of the cities set forth.

When the industrial level is investigated, the same trends are indicated. Tables 3 and 4 give similar statistics for the industrial level as has been previously set forth for the domestic level. It will be noted that in 30 cities there have been substantial increases in coal and fuel oil prices, while the greater part of the same locations saw the average price of natural gas decline. In those locations where the price of natural gas increased, the increase in the price of coal and fuel oil was considerably greater. In the 30 cities shown, only two found oil cheaper than natural gas; and there are many cities in which natural gas is now cheaper than coal on the industrial level without allowance for the greater burning efficiency possible with natural gas.

The trends since the heating season of 1947-1948, the time of these comparisons is set forth as follows: Without exception, the average prices of solid fuels and all grades of oil used by utilities showed increases during 1948 in adidtion to those experienced during the previous year. During the early part of 1949, oil prices, particularly for the heavier grades, have decreased and even coal prices have given indications of falling slightly which makes the statistics on price comparisons set forth herein of conservative nature when predicting price levels for the present heating season.

*Presented before the Independent Natural Gas Association of America, Dallas, Texas, October 31, 1949.

†Director, Division of Engineering, Texas College of Arts and Industries, Kingsville, Texas.

[1]In this paper, sources of energy supply are available from the Bureau of Mines through 1947 and these price statistics are also quoted at this time. Later in this paper present price levels have received comment.

TABLE 1. Percentage change in prices per million Btu of gas, coal, and fuel oil for house heating, third quarter 1947, compared to 1940.

City	Natural gas* Btu/cu ft	Natural gas (Per cent change)	Coal (Per cent change)	Fuel oil (Per cent change)
Washington, D.C.	1100	+ 4.0%	+68.2%	+51.8%
Pittsburgh	1100	— 0.6	+97.6	....
Columbus	1030	0.0	+77.6[1]	+59.9
Cleveland	1100	— 4.6	+76.9	+59.9
Detroit	1002	— 0.2	+94.5	+74.3
Peoria	1000	+ 4.6	+85.1[1]	....
Des Moines	1000	—10.7	+36.0[2]	+35.9[1]
Cheyenne	1000	—14.2	+43.5[3]	....
Denver	1000	—21.1	+95.3[3]	....
Atlanta	1000	— 0.5	+100.4	....
Memphis	960	0.0	+79.8	....
Mobile	1050	—28.9	+47.3[4]	....
New Orleans	1065	—44.5	+58.4	+45.1
Kansas City, Missouri	1025	—10.2	+68.2	+46.9
Wichita	1000	—24.2	....	....
Little Rock	1000	—23.3	....	....
Dallas	1000	—20.6	....	....
Houston	1000	—18.1	....	....
Butte	1000	0.0	+39.2[2]	....
Salt Lake City	875	0.0	+52.1[1]	....
Phoenix	1057	—27.4	....	....
San Francisco	1100	—28.6	+21.0[5]	+58.2[6]
Los Angeles	1100	— 2.1	....	....

City	Manufactured* or mixed gas Btu/cu ft	Gas (Per cent change)	Coal (Per cent change)	Fuel oil (Per cent change)
Binghamton	850	0.0%	+66.4%	+41.2%
Buffalo	900	0.0	+56.9	+73.5
Rochester	537	— 4.5	+50.0	+52.9
Philadelphia	530	+19.7	+60.8	+49.2
Cincinnati	1000	— 9.0	+84.3	+59.9
Louisville	900	+ 0.3	+66.2[1]	....
Indianapolis	570	0.0	+67.8	+47.8
Chicago	800	0.0	+71.2	+42.4
St. Louis	800	0.0	+71.8	+59.7
Minneapolis	875	—15.7	+79.5	+46.5
Omaha	600	—10.0	+34.2[1]	+45.9[1]
Birmingham	540	0.0	+111.5	....

* Based on 1947 distribution.
[1] 2nd quarter 1947 compared to 1940.
[2] 2nd quarter 1947 compared to 1941.
[3] 3rd quarter 1947 compared to 1941.
[4] 4th quarter 1946 compared to 1940.
[5] 3rd quarter 1946 compared to 1940.
[6] 3rd quarter 1947 compared to 1944.
SOURCE: Independent Natural Gas Association of America.

TABLE 2. Comparative prices of gas, coal, and fuel for house heating based upon prices for third quarter, 1947.

City	Natural gas Btu/cu ft	Gas (Cents per million Btu)	Coal (Cents per million Btu)	Fuel oil (Cents per million Btu)	Coal and fuel oil prices compared to gas (gas=100) adjusted for burning efficiency: Coal (Per cent)	Fuel oil (Per cent)
Washington, D.C.	1100	104.0	39.7	76.5	45.5	80.0
Pittsburgh	1100	52.3	33.4	....	76.1	.....
Columbus	1030	48.5	38.0[1]	89.2	93.2	200.0
Cleveland	1100	50.0	49.7	89.2	118.4	194.0
Detroit	1002	62.0	49.6	85.6	95.2	150.0
Peoria	1000	57.2	32.4[1]	....	67.5	.....
Des Moines	1000	60.3	35.1[1]	73.1[1]	69.3	131.8
Cheyenne	1000	40.4	40.9[1]	....	120.5	.....
Denver	1000	37.7	37.3	....	117.8	.....
Atlanta	1000	60.0	47.5	....	94.2	.....
Memphis	960	52.7	45.3	....	102.3	.....
Mobile	1050	48.1	....	....	.....	.....
New Orleans	1065	54.7	59.1	71.4	128.7	141.9
Kansas City, Missouri	1025	44.7	39.2	73.6	104.5	178.9
Wichita	1000	37.6	....	....	.....	.....
Little Rock	1000	43.1	....	....	.....	.....
Dallas	1000	53.6	....	....	.....	.....
Houston	1000	57.6	....	....	.....	.....
Butte	1000	45.0	38.7[1]	....	102.4	.....
Salt Lake City	875	50.7	32.4[1]	....	76.1	.....
Phoenix	1057	50.3	....	....	.....	.....
San Francisco	1100	33.7	....	64.4	.....	207.7
Los Angeles	1100	45.9	....	....	.....	.....

City City	Manufactured or mixed gas Btu/cu ft	Gas (Cents per million Btu)	Coal (Cents per million Btu)	Fuel oil (Cents per million Btu)	Coal and ruel oil prices compared to gas (gas=100) adjusted for burning efficiency: Coal (Per cent)	Fuel oil (Per cent)
Binghamton	850	66.3	46.6	81.6	83.7	133.8
Buffalo	900	68.6	34.2	83.1	59.3	131.6
Rochester	537	96.4	50.4	78.7	62.2	88.7
Philadelphia	530	113.2	49.7	70.5	52.3	67.7
Cincinnati	1000	50.7	42.2	89.2	99.0	191.3
Louisville	900	57.5	34.9[1]	....	72.2	.....
Indianapolis	570	76.3	38.6	80.1	60.3	114.2
Chicago	800	70.0	53.4	77.3	90.9	120.0
St. Louis	800	64.1	42.6	77.3	79.1	131.1
Minneapolis	875	62.9	58.7	79.4	111.1	137.2
Omaha	600	83.3	42.0[1]	72.2[1]	60.0	94.2
Birmingham	540	76.8	44.0	....	68.2	.....

[1] Prices for 2nd quarter 1947 used.
SOURCE: Independent Natural Gas Association of America.

Natural and Manufactured Gas

In this study, mixed gas is considered as manufactured gas and its price at various locations is compared with coal and fuel oil. Manufactured gas is produced by using coal, coke, or various petroleum products as a basic raw material. Therefore, it is only natural that the price of manufactured gas will be greater than the price for primary fuels in the same locality, as would be the price of manufactured gas blended with natural gas (mixed gas). Thus the competitive picture of natural gas versus manufactured gas may partly be foreseen when each of these fuels are compared with the primary fuels, coal and fuel oil, at the locations in question.

The picture of manufactured gas compared to coal and fuel oil on the domestic and industrial levels is also shown in Tables 1, 2, 3, and 4. It will be noted that again gas prices have not increased as have the primary fuel. However, straight manufactured gas is not in the same position to compete with these fuels as is natural gas or mixtures containing appreciable quantities of natural gas (gas with 540 Btu or lower). Of the three manufactured gases reported, it will be noted on the domestic level that one price has not changed although one has decreased by 4.5 per cent and the other has increased 19.7 per cent. In the latter case, this system has changed and is now using natural gas as a blending agent.

Companies producing straight manufactured gas have been faced with rising costs of raw materials like coal and oil and the cost of the manufactured gas has been held to a minimum only by temporary rigid economy measured and fuel clauses. Fuel clauses permit only a limited variation in utility gas rates without the necessity of further formal regulatory commission action. Such action is taken on the basis of some mathematical relationship to the cost of the raw material with most of the fuel clauses dependent upon the price of oil. In general, the answer to their problem appears to be the use of natural gas as a blending agent or as a straight distribution product. At the present time it is not economical in straight production practices to make gas with a higher Btu content than about 550 per cubic foot. A change to a higher Btu gas by using natural gas not only has economic advantages, but technologic as well, as the increase in system capacity varies directly as the increase in Btu content. When 1000 Btu natural gas replaces manufactured gas of 500 Btu content, the system not only

TABLE 3. Percentage change in prices per million Btu of gas, coal, and fuel oil for industrial purposes, third quarter 1947, compared to 1940.

City	Natural gas* Btu/cu ft	Natural gas	Coal	Fuel oil
		(Per cent change)		
Detroit	1001	−25.4[1]	+100.7	+118.7
Toledo	1050	+16.1	+ 90.1	+123.8
Cleveland	1100	+ 7.0	+ 86.3	+136.1
Pittsburgh	1118	+11.8	+ 59.4	+ 57.1
Columbus	1050	+ 9.3	+116.7	+157.6
Cincinnati	1025	− 6.7	+117.3	+193.1
Fort Wayne	1000	− 9.8	+ 74.2	+ 78.4
Chicago	1047 and 1034	+29.1	+ 61.1	+111.2
Peoria	1001[2]	+22.3[3]	+101.1	+108.9
St. Louis	991	+11.2	+64.4	+122.1
Kansas City, Missouri	1025	+10.1	+ 78.4	+235.5
Lincoln	1002	− 2.9	+ 51.3	+107.2
Des Moines	1000	−72.6	+ 71.4	+109.8
Minneapolis	1003	−18.4	+ 51.1	+ 91.3
Salt Lake City	875	− 3.7	+ 65.0	+ 35.7
Cheyenne	978	....	+ 49.0	+188.9
Denver	978	−10.5	+ 71.1	+110.5
Nashville	1070	−46.6	.....	+ 49.3
Memphis	985	+ 6.2	.....	+ 66.4
Atlanta	1022	− 4.5	+ 78.4	+ 35.5
Birmingham	1022	− 3.6	+ 91.1	+ 38.9
Jackson	1048	−17.5	.....	+ 61.0
Mobile	1048	−17.5	+ 64.0	+ 57.3
New Orleans	1075	−31.6	.....	+ 92.9
Houston	1075	−31.6	.....	+113.1
Dallas	1060	− 9.3	.....	+113.1
Little Rock	1000	−25.0	.....	+ 93.8
Wichita	1010 and 1040	−10.0	.....	+235.5
El Paso	1070	−19.0	.....	+136.6
Phoenix	1102	− 4.5	.....	+ 72.6

City	Manufactured* or mixed gas Btu/cu ft	Gas	Coal	Fuel oil
		(Per cent change)		
Buffalo	840	....	+ 91.7	+147.8
Binghamton	850	− 2.7	+ 61.3	+ 61.1
Philadelphia	530	+ 8.9	+ 74.8	+ 79.4
Erie	904	+ 4.7	+100.8	+ 56.8
Cincinnati	1025	− 6.7	+117.3	+193.1
Louisville	900	− 0.8	+ 77.6	+ 86.1
Omaha	1000 and 600	− 4.3[1]	+ 60.1	+109.8

* Based on 1947 distribution.
[1] 1946 compared to 1940.
[2] Average for second quarter 1947.
[3] 2nd quarter 1947 compared to 1940.
SOURCE: Independent Natural Gas Association of America.

doubles in capacity due to the thermal concentration, but by belting the outlying districts and back-feeding a distribution capacity may be increased fourfold.

During 1948 the total number of consumers using manufactured and mixed gas declined from the previous year. This decline was due in part to the change-over to natural gas of several large utilities. To a lesser extent it was due to the fact that most manufactured gas companies added fewer new heating customers in 1948 than in the preceding year.

In studying the financial status of gas companies, as industry expansions are not available, the ratio form will be used. Here natural gas and manufactured operating utilities are each defined as having at least 95 per cent of their operating revenue from that respective type of gas. In the comparison over a 12-year period the total number of companies will vary. For manufactured gas there were 124 with a total operating revenue of $92,000,000 in 1937 and 63 companies with $167,000,000 in 1948. Likewise, for natural gas there were 95 companies with a $287,000,000 revenue in 1937, and 1948 saw 154 companies with 1072 million dollars revenue. Thus the financial predicament of

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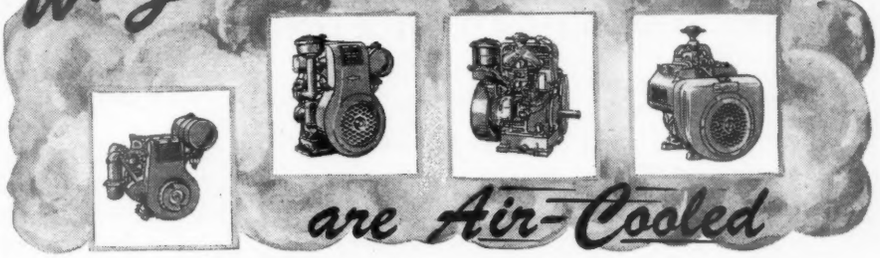

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TABLE 4. Comparative prices of gas, coal, and fuel oil for industrial purposes based upon prices for third quarter, 1947.

City	Natural gas Btu/cu ft	Gas	Coal	Fuel oil	Coal and fuel oil prices compared to gas (gas=100) Coal	Fuel oil
		(Cents per million Btu)			(Per cent)	
Detroit	1001	....	27.7	56.2	.....	.....
Toledo	1050	36.1	27.0	46.1	74.8	127.7
Cleveland	1100	36.8	24.4	54.3	66.3	147.6
Pittsburgh	1118	32.3	15.3	52.8	47.4	163.5
Columbus	1050	37.7	26.0	55.9	69.0	148.3
Cincinnati	1025	44.4	22.6	51.0	50.9	114.9
Fort Wayne	1000	53.7	27.7	56.2	51.6	104.7
Chicago	1047 and 1034	19.1	23.2	53.0	121.5	277.4
Peoria	1001[1]	27.4[2]	18.5	51.4	67.5	187.6
St. Louis	991	18.9	21.7	49.3	114.8	260.8
Kansas City, Missouri	1025	15.3	19.8	35.9	129.4	234.6
Lincoln	1002	16.9	23.6	48.7	139.6	288.1
Des Moines	1000	17.5	24.0	49.3	137.1	281.7
Minneapolis	1003	20.4	28.4	53.0	139.2	259.8
Salt Lake City	875	13.1	22.6	31.2	172.5	238.2
Cheyenne	978	34.2	24.6	31.2	71.9	91.2
Denver	978	15.3	21.9	32.2	143.1	210.5
Nashville	1070	56.4	....	50.0	.....	88.7
Memphis	985	18.8	....	38.6	.....	205.3
Atlanta	1022	17.1	24.8	46.2	145.0	270.2
Birmingham	1022	16.2	21.4	43.0	132.1	271.0
Jackson	1048	13.7	....	40.4	.....	294.9
Mobile	1048	13.7	22.8	43.9	166.4	320.4
New Orleans	1075	9.1	....	29.9	.....	328.6
Houston	1075	9.1	....	32.6	.....	358.2
Dallas	1060	13.7	....	32.6	.....	238.0
Little Rock	1000	10.5	....	46.7	.....	444.8
Wichita	1010 and 1040	10.8	....	35.9	.....	332.4
El Paso	1070	20.1	....	36.2	.....	180.1
Phoenix	1102	16.9	....	45.9	.....	271.6

City	Manufactured Btu/cu ft				Coal and fuel oil prices compared to gas (gas=100)	
		(Cents per million Btu)			(Per cent)	
Buffalo	840	64.7	25.5	51.3	39.4	79.3
Binghamton	850	88.2	27.9	50.9	31.6	57.7
Philadelphia	530	112.8	28.5	39.1	25.3	34.7
Erie	904	55.9	25.3	53.3	45.3	95.3
Cincinnati	1025	44.4	22.6	51.0	50.9	114.9
Louisville	900	37.8	20.6	53.6	54.5	141.8
Omaha	1000 and 600	....	26.9	49.3	.....	.....

[1] Average for second quarter 1947.
[2] Prices for second quarter 1947 used.
SOURCE: Independent Natural Gas Association of America.

manufactured gas companies and their competitive position with natural gas companies shows a decrease in net income of the former over a period of years, brought about largely by operating expenses, the greater proportion of which has been the price of raw materials like coal and fuel oil. As previously pointed out, one solution is the use of natural gas and, wherever it is available, conversion to mixed or straight natural gas. Thus the increased price of coal and fuel oil has not only allowed natural gas to gain on a competitive basis with them, but has also permitted natural gas to gain on manufactured gas derived chiefly from these costly primary fuels.

The continued marked post-war expansion of the gas utility industry is revealed by the statistics of construction expenditures that during 1948 attained the unprecedented level of 769.6 million dollars. Even when the inflated level of construction costs are accounted for, this industry has been and will be carrying out the greatest expansion of physical facilities in its history. It will be noted that although a considerable expenditure of a somewhat constant amount is going for distribution, production, and storage, etc., by far the greater emphasis continues to be centered on natural gas

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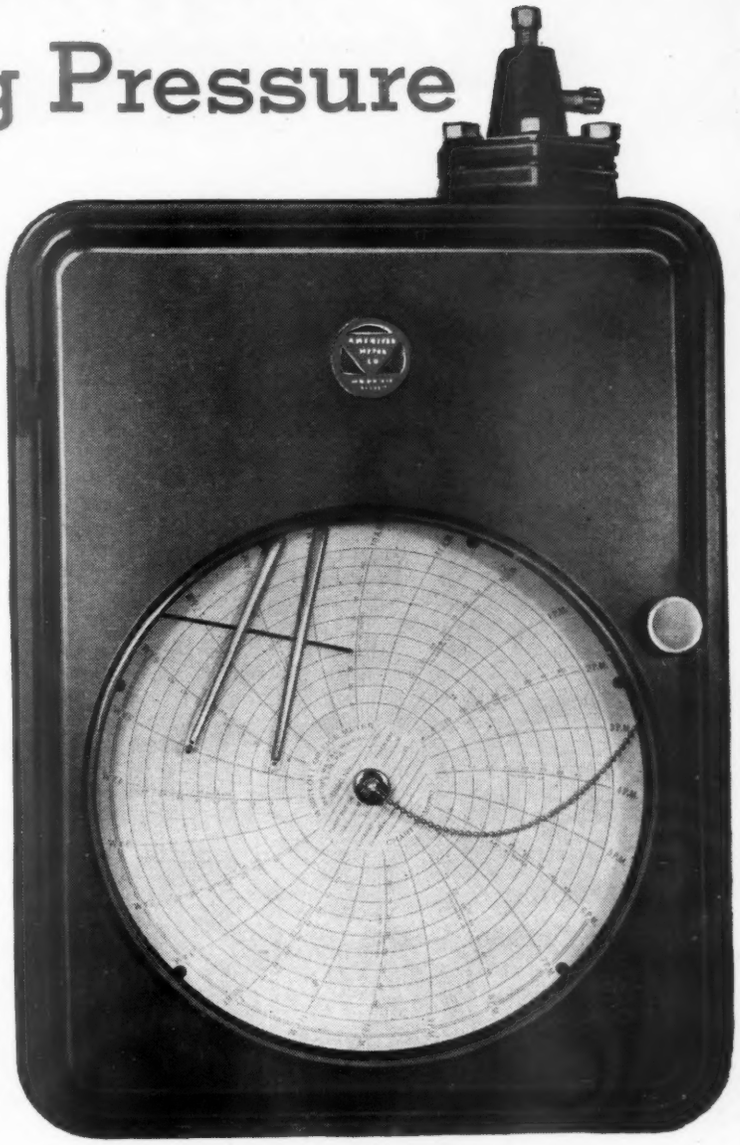

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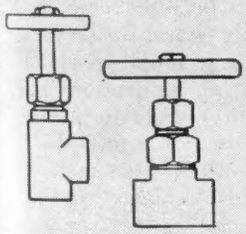

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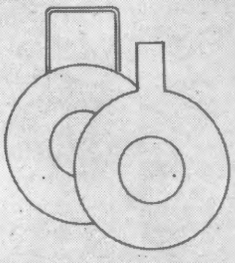

ORIFICE PLATES AND ORIFICE FLANGES
(Bulletin EG-2)

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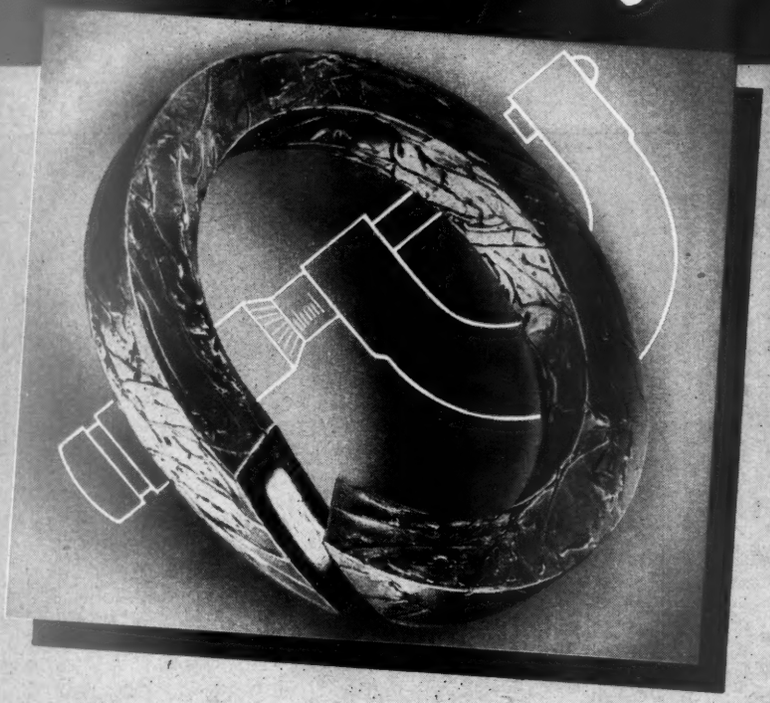

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transmission systems, which in 1948 was equivalent to approximately 50 per cent of the entire gas utility industry expenditure. In 1951 and 1952, the greater part of the over-all expansion of natural gas transmission lines should be completed and natural gas, without doubt, will then experience the most desirable position in its competition with manufactured gas and other fuels.

Atomic Energy as a Competitive Fuel

Under the active stimulus of war, the first major application of atomic energy release has been that in the form of the atom bomb. This energy release whereby one pound of atomic fuel is equivalent to 1500 tons[3] of coal or 40 million cubic feet of natural gas immediately becomes of great importance in the fuel picture of the nation if technology can now control these forces and turn them to man's use rather than to his destruction.

When atomic energy is applied as a fuel, naturally the beginning point is heat that may be picked up by water, air or special heat transfer fluids. This heat in turn could be applied directly, or converted into electricity or mechanical power by present-day steam or gas turbines. The use of intermediate heat transfer fluids to protect against radioactivity would permit its use for space and water heating also. The above applications of heat derived from atomic energy would require varying operating temperatures. Although present atomic piles run at low temperatures, it is evident that temperatures high enough for the efficient operation of steam and gas turbines will be realized as the concentration of the atomic mass of the piles is increased. As the concentration of the pile increases so does the cost, and although experimental atomic power plants are being actively considered today, we may not expect experimental ships or submarines to be active before 10 years. Certainly we can not expect to see this source of energy competing with those discussed in this paper before another 30 years. Only then may this be possible should sufficient deposits of atomic raw materials be discovered and national controls permit such a technical and economic accomplishment. These first commercial applications may be looked for in remote locations like Arctic airports or other locations where the transportation costs of the raw material would be a deciding factor. Another application could be as a premium fuel for the propulsion of aircraft or missiles in which minimum

[3] "The Atom, New Source of Energy," McGraw-Hill Publishing Company, 1945.

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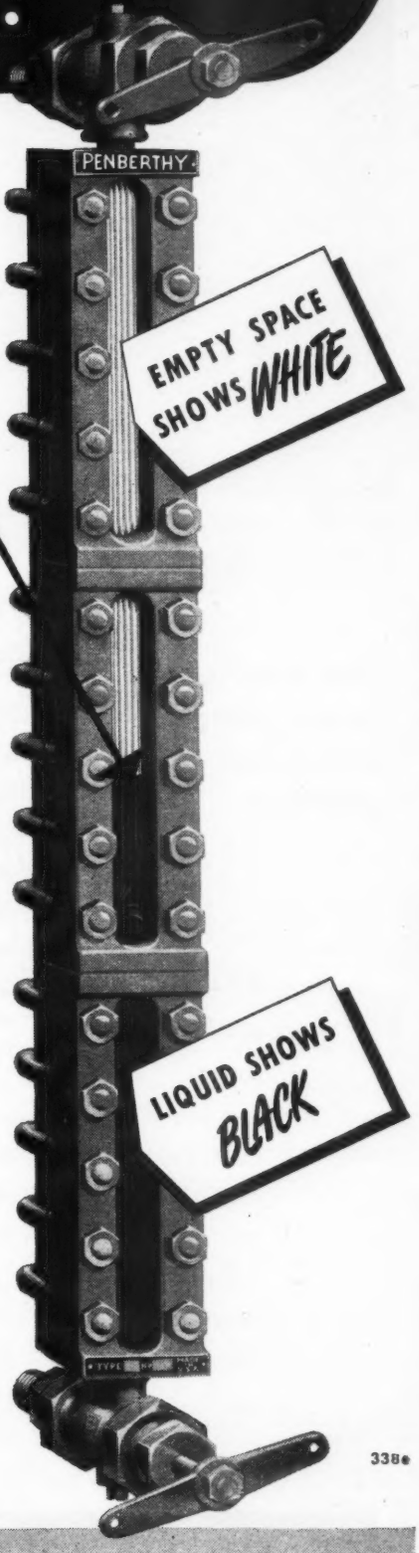

The refraction of light (an unvarying law of nature) makes the reading of Penberthy Reflex Gages unmistakable. Due to this refraction principle, the empty space always shows white—the space occupied by liquid always shows black. The dividing line between liquid and empty space is sharp and unmistakable, there can be no error in reading. It is easily read as far as you can distinguish between black and white.

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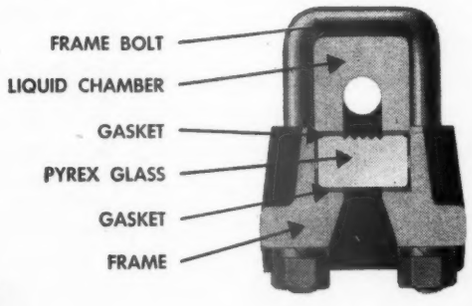

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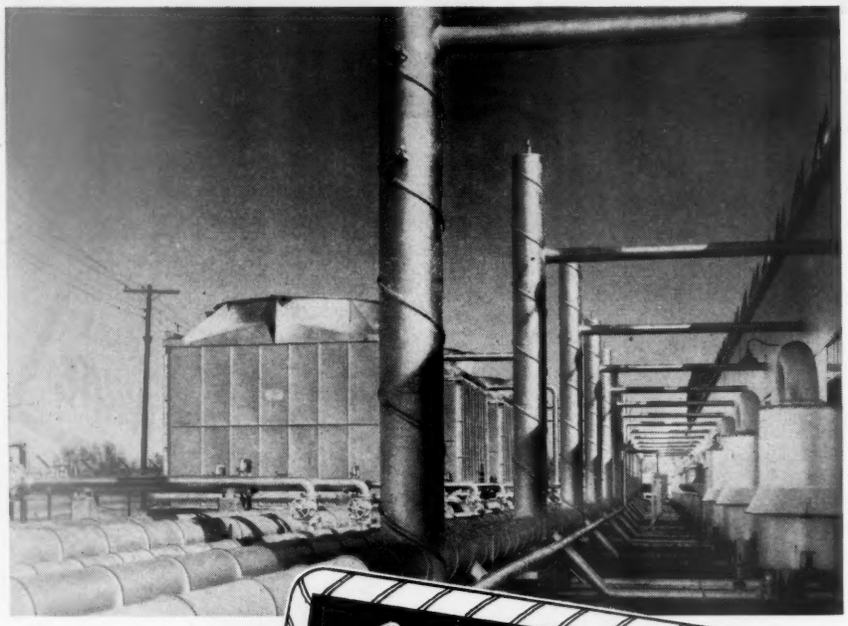

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weight or similar characteristics are the controlling factors that could support a high price.

Summarizing, in the future the application of atomic energy during times of peace may be as staggering as it has been in the past during times of war. It appears, however, that if it becomes a competitor to the fuels discussed herein, natural gas will be the least affected and the last of all to experience active competition.

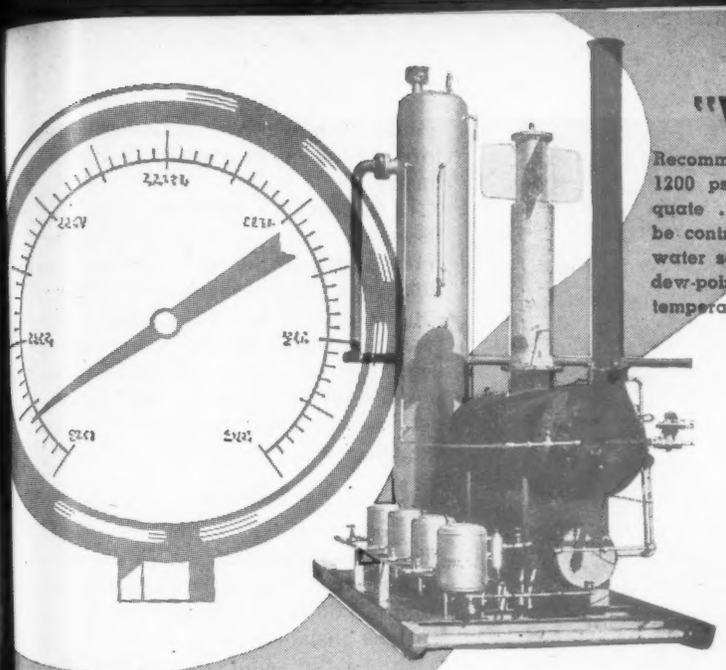
Technological Trends

The close association of petroleum and natural gas from their production through their end uses in many instances partially reflects the similar relationship that exists in their fields of technology and development. It has been an active program of research and development that has insured ever-increasing production efficiency, transportation, processing, and utilization of these so-called twins. Thus, trends in technology should not alter the comparative position of either of these fuels from the competitive standpoint as set forth herein.

A marked difference is seen when natural gas is compared to manufactured gas. Today natural gas replaces manufactured gas because, with the price of raw materials, present processes do not allow manufactured gas to compete with natural gas except in locations remote from the natural gas fields. But each day the developments in long-distance transmission-line techniques reduce this remoteness, allowing natural gas to continue its economic inroads on manufactured gas. Thus, to retrieve this loss, processes must be developed to produce a high Btu gas capable of competing with natural gas. The manufactured gas industry has been active in production research problems. Satisfactory processes for catalytically cracking natural gas and heavier hydrocarbon mixtures for a higher Btu mixed gas for distribution and for peak loads have been developed. In addition, a new high Btu oil gas process is now in operation to produce oil gas to replace natural gas in peak shaving or for enrichment operations. These new processes, it should be noted, employ liquid or gaseous hydrocarbon raw materials.

The gasification of our solid fuels in place or their production and gasification in the field are presently being actively investigated and offer potential competition to natural gas.

It seems, however, that the current price of solid raw materials and production costs will delay the time such operations can be put on a commercial scale. Such technologic and eco-



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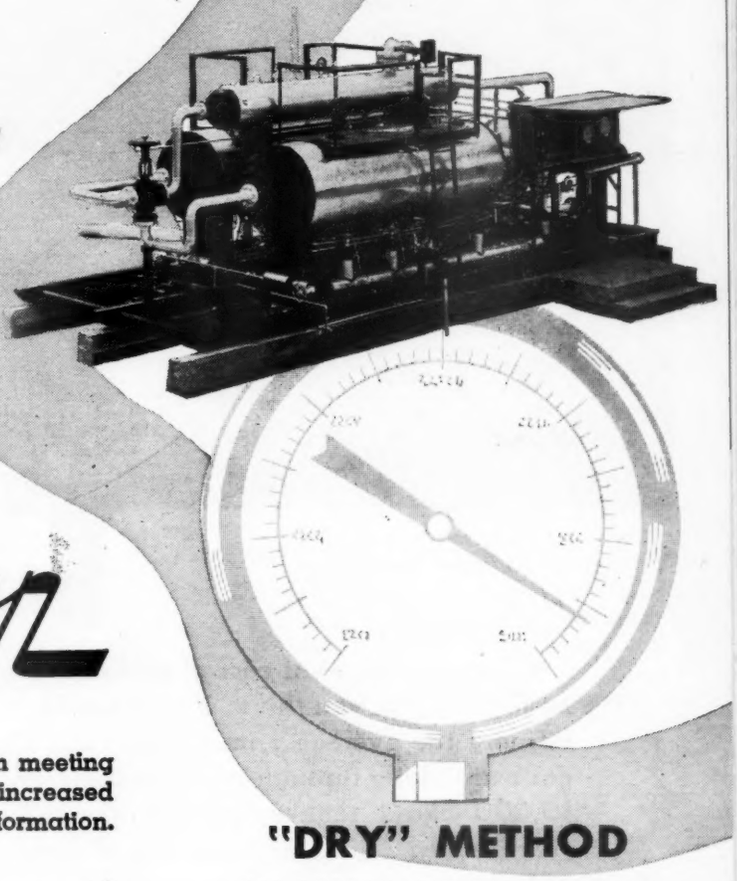
Recommended for operating pressures up to 1200 psi, where partial dehydration is adequate . . . or where gas temperature can be controlled. Concentrated triethylene glycol-water solutions serve as desiccant. Provide a dew-point depression 60° to 75° F below gas temperature! Low in cost.



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Dehydration

Up go gathering and transmission line pressures in meeting today's vastly greater demand for natural gas. But increased pressures mean increased troubles from hydrate formation. UNLESS there's a BS&B Dehydrator on the job!

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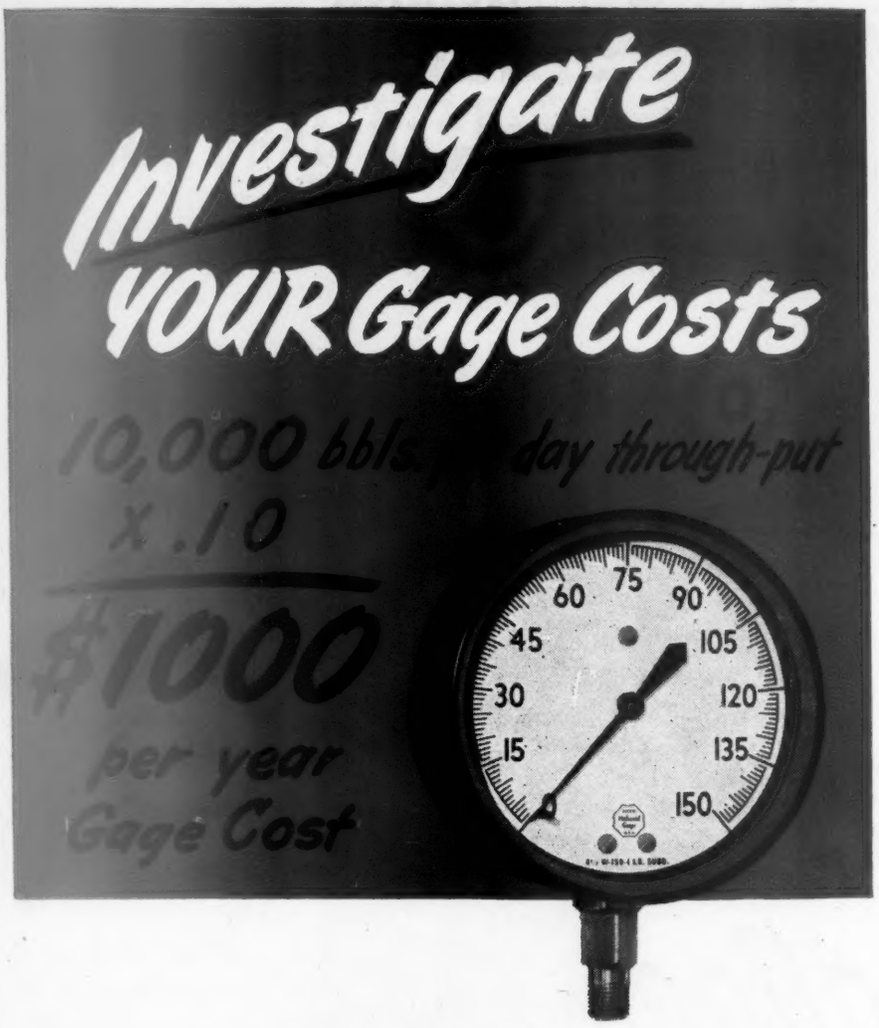

● Your replacement cost of pressure gages may be higher than you think. For example, in an oil refinery the average annual cost runs about 10¢ per barrel daily through-put. On that basis, a small 10,000 barrel refinery spends about $1000 a year for new gages. And the cost of parts, repairs and maintenance is much higher.

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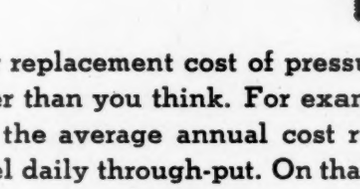

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nomic changes seem improbable before the advent of a synthetic-fuel industry.

If technologic advances speed up, however, we may see transmission lines handling not only natural gas but a high Btu gas manufactured from solid fuels with a varying point in the pipe line where the delivered cost of each fuel would be the same. This point would vary as the cost of production and transmission of each type of gas.

Conclusion

It has been shown that there have been substantial increases in the price of coal and fuel oil throughout the country although natural gas prices in most instances have decreased or remained the same. In the very few instances where natural gas has increased in price, there has been a much greater increase in the price of coal and fuel oil. As a result, the relative advantages in the price of coal and oil for domestic and industrial use has been narrowed to the point that in many cases natural gas is now cheaper than either fuel oil or, in other localities, cheaper than coal. Natural gas presently experiences similar advantages over the manufactured gas which is derived from coal and oil. Considering that natural gas is advantageous from the standpoint of convenience, cleanliness, and its high Btu content, the latter in reference to manufactured gas, it is to be expected that the trend now being experienced will continue so that there will be a constantly growing demand for natural gas in preference to either coal, oil, or manufactured gas.

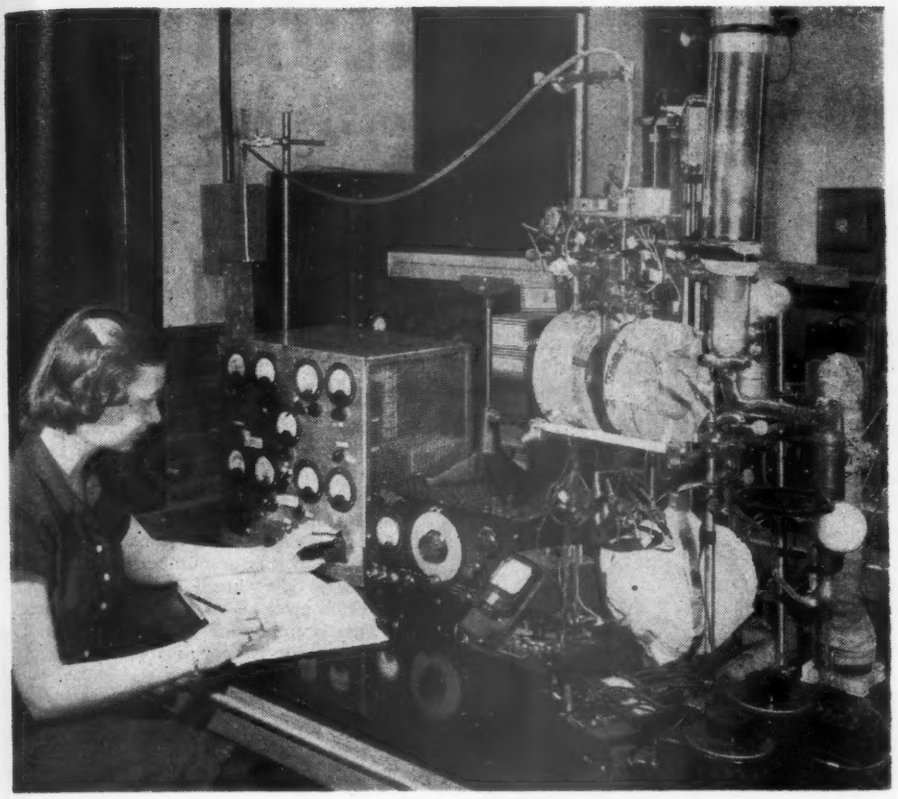
It has also been shown that the introduction of a new form of energy, such as atomic energy, and new processes for the production of gas from solid or liquid fuels will not appreciably affect the ever-increasing role that natural gas will play in the total fuel picture of this nation in the years to come.

Acknowledgment

Acknowledgment is hereby made to John A. Ferguson, executive director of the Independent Natural Gas Association of America, for helping in the preparation of this paper and for making available certain basic data. To H. Carl Wolf, managing director of the American Gas Association, for permission to reproduce graphic materials from *Gas Facts*, gratitude is expressed.

* * *

High-quality petroleum lubricants add years to the useful life of the average passenger car. At the end of 1949 the average car on the road was 8.4 years old. The pre-war average figure was 5.5 years.



The three-stage nonmagnetic mass spectrometer in experimental operation at the National Bureau of Standards.

Three-Stage Nonmagnetic Mass Spectrometer

A THREE-STAGE nonmagnetic mass spectrometer, employing the principle of velocity selection, has been developed by Dr. Willard H. Bennett of the National Bureau of Standards. In the new spectrometer a radio-frequency field replaces the usual magnetic field. Combining unusually simple operation with small size, light weight, and high sensitivity, the instrument has promising applications in several fields of science and industry.

In ordinary mass spectrometers a high intensity beam of ions is bent in the field of a large iron magnet, passed through a narrow slit, and then focussed accurately on a narrow receiving slit. The nonmagnetic mass spectrometer uses neither bending nor focusing. Ions produced in the ionization chamber travel in parallel paths through the tube, a glass cylinder 8 in. long and 2 in. in diameter. Three sets of three tungsten-wire grids are spaced along the tube to form the three stages. A radio-frequency potential is applied to the middle grid in each stage. An additional grid, with a negative potential applied, follows the final stage and in the absence of r-f potential turns back any electrons that may have arisen anywhere along the tube. Following the final grid is a collector plate whose potential is sufficiently positive to repel all but the desired positive ions.

The distances between grids and between stages are selected very accurately so that for any particular ion mass there will be a single definite frequency of the radio-frequency potential, which can speed up ions of that mass as they pass through each stage. The increased speed of these ions enables them to overcome the opposing potential on the collector while all other kinds of positive ions are turned back. Successive distances between stages must be chosen so that the r-f potential will complete an exactly integral number of cycles during the time it takes for an ion of the desired mass to travel between stages, picking up maximum energy in each stage. The best combination of these integral numbers for a three-stage tube turns out to be 7 and 5, and in actual operation the 7-and-5 cycle tube has completely separated the isotypes of chlorine. From this observation it is estimated that a four-stage tube, using integral numbers 13, 11, and 7 should resolve masses differing by only one per cent.

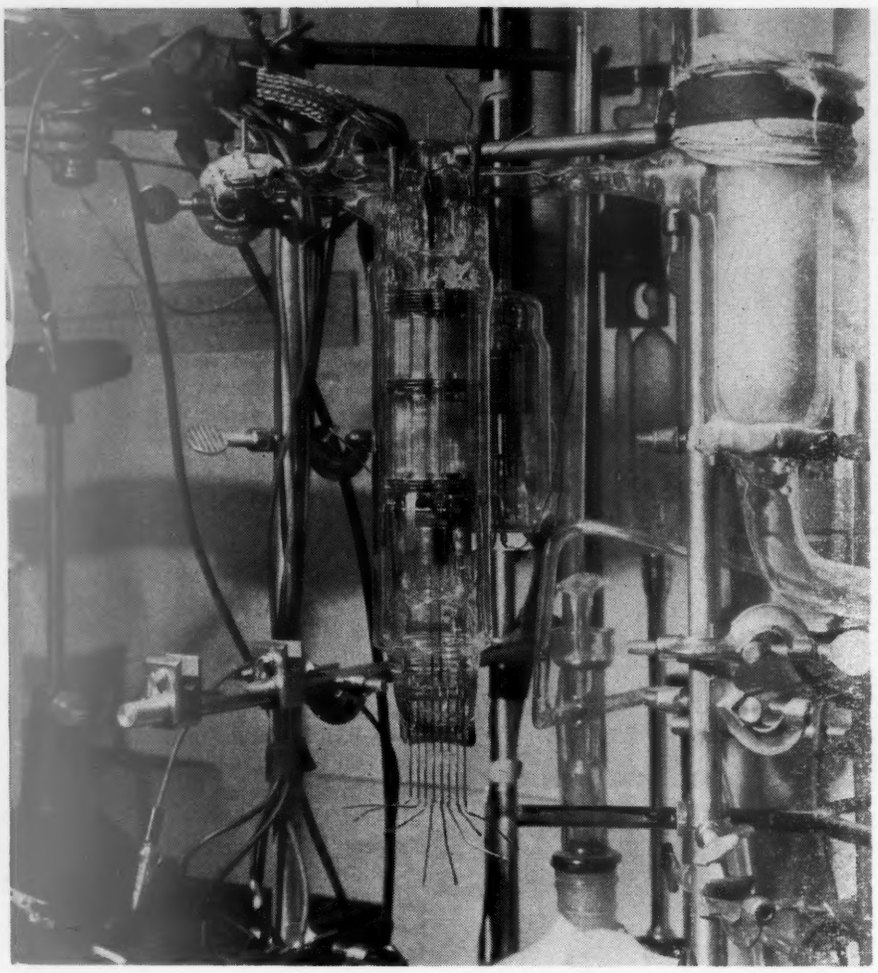
The spectrometer can make use of all the ions that can be made to emerge through a grid several centimeters in diameter, and a new kind of positive ion source has been developed to take advantage of this. A spiral filament delivers an ionizing electron current of 100 milliamperes through a double grid attached at one end of a hollow metal cylinder 3 centimeters deep. The far end is closed by a grid and near it is another grid at a negative potential that turns back all electrons and draws positive ions out from the cylindrical enclosure. At a pressure of 4 by 10^{-5} millimeters of mercury the source delivers a positive ion current of 100 microamperes.

By an appropriate change in ion source and reversal of potentials, the spectrometer works well for the study of negative ions, an important feature of the new instrument. As negative ions are in general much less abundant, when they exist at all, the unusual sensitivity of the Bennett spectrometer is a great advantage in the study of negative ions.

In the development of vacuum tubes as for example power transmitting tubes such a spectrometer can be very helpful in analyzing gases and vapors that are evolved from the heated electrodes.

Surface reactions are another group of processes for which the new spectrometer can be used, separately analyzing the positively or negatively charged components. In gaseous discharges, the instrument can be used for direct analysis of the ions without magnetically disturbing the discharge.

One of the urgent needs of the U. S. Bureau of Mines is an instrument that can be used in the field for the analysis of small percentages of hydrogen in



Close-up of a completed three-stage nonmagnetic mass spectrometer tube developed by Dr. Willard H. Bennett at the National Bureau of Standards. Three sets of tungsten-wire grids are spaced along the tube to form the three stages. A radio-frequency potential applied to the middle grid in each stage speeds up ions of the desired mass enabling them to reach the collector.

the manufacture of helium. The new spectrometer has already demonstrated adequate sensitivity and resolution for this task, and it can be readily adapted to automatic operation. Similarly, the new instrument could be used for continuous observation of the air in an enclosed space, giving warning of the presence of dangerous components such as hydrogen or chlorine. In addition, an active project is now under way at the National Bureau of Standards to adapt this instrument for use as an extremely sensitive carbon monoxide detector.

The lightness and compactness of the nonmagnetic spectrometer offers a way to settle the question of the chemical composition of the upper atmosphere. This is a problem that is directly related to work in radio propagation and stratospheric flight. Arrangements have been made with the Applied Physics Laboratory of the Johns Hopkins University to send one of the new spectrometers aloft in a rocket. Before it is mounted in the rocket, the spectrometer tube will be evacuated and sealed; when the rocket has reached maximum altitude, an arm of the tube will be broken open to the rarefied air. The relative densities of atmospheric components will then be telemetered back to the ground for recording.

The nonmagnetic mass spectrometer is now being adapted to the rapid scanning of mass spectra. Present methods permit sweeping twice a second through the mass range from 10 to 50, displaying the measured mass components directly on the screen of a cathode-ray oscilloscope. The scanning is accomplished by sweeping the ion accelerating voltage from 50 to 250 v while modulating the radio-frequency potential with a 1000-cycle signal. * * *

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In recent years, aluminum and aluminum alloys have grown rapidly in importance as piping materials in many industries, including manufacturers of chemicals, foods, soaps and cosmetics, petroleums, textiles, explosives, rubber, paints and varnishes.

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For example, in chemical plants, aluminum offers great resistance to corrosion, and it is passive to a large number of corrosive fluids where other metals tend to catalyze. Its corrosion products do not cause discoloration. This is important where maintenance of product color is of primary importance.

In food plants, aluminum resists the corrosive action of most food products such as acetic and nitric acids, oils, milk, beer, and fruit juices. It protects against color contamination and helps prevent rancidity.

In the petroleum industry, aluminum piping resists the corrosive action of hydrogen sulfide, sour crude oils, mineral oils and liquid fuels.

Aluminum piping materials are available in a variety of alloys including 2S, 3S, 61S, 63S, and Alclad 3S. Each is particularly suited for certain applications. And, since the physical properties vary with each alloy used, individual applications should be analyzed carefully to determine the correct alloy needed for the job.

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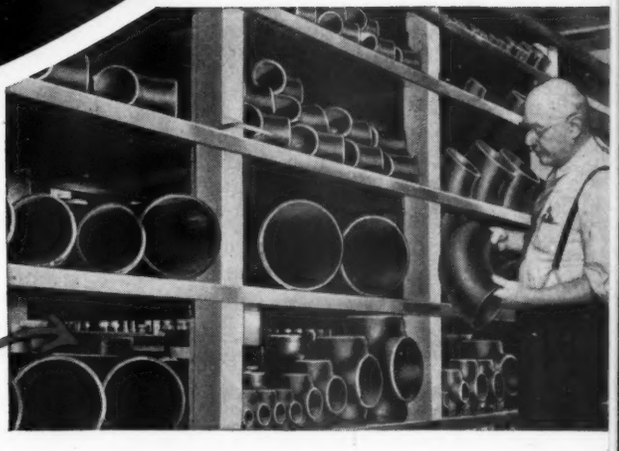

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Research in the Petroleum Industry*

Oil companies have been highly successful in creating new products and improving old ones while at the same time developing efficient methods that hold costs down.

F. L. MILLER†

MR. REEVES has explained to you the organization and functions of the Standard Oil Development Company, and Mr. Kunc and Dr. Tongberg reviewed several interesting developments in the fuels and lubricants fields. My purpose is to review more broadly a few of the important contributions of the petroleum industry —and of the Development Company— to petroleum technology, and to mention some of the developments that may be anticipated in the future.

The oil industry has come a long way from the early days when gasoline was practically a by-product of the kerosine business, and axle grease was one of the most important lubricants.The automobile and the airplane (as we know them today) have been made possible because research men in the oil industry were able to make readily available the proper types of liquid fuels and lubricants. And the fuels particularly had to be available in large quantity at low cost if the great mass of our people were to use these machines. The petroleum industry has succeeded in both of these tasks. In the past 20 years, the supply of gasoline has increased from 337,000,000 bbl per year in 1928, to 896,000,000 bbl in 1948, while the quality, as expressed by octane number, has increased from 60 to around 84 on regular grade gasoline. For example, the modern automotive engine could not operate satisfactorily on the 1928 gasoline. Yet the price, exclusive of tax, was little or no greater in 1948 than it was in 1928. This is a record of technological progress that is difficult to match.

The story behind modern gasoline well illustrates the accomplishments of petroleum research. As you know, the efficiency of spark ignition engines is largely determined by compression ratio. The higher the compression ratio, within certain limits, the better the performance of the engine. But higher compression ratios require higher octane-number gasolines for satisfactory operation, and much of the improvement in automobile engines has been the combined result of the efforts of the motor manufacturers to raise the compression ratio, and of the fuel manufacturers to develop better gasoline so that higher compression ratios could be useful to the general public.

Over the past 20 years, the average efficiency of automobile engines has increased about 35 per cent. About half of this increase has been due to increase in compression ratio; the other half has been due to various other improvements in the engine.

In the same time, as I said before, the quality of motor gasoline, as measured by octane ratings, has increased for regular grade gasoline from 60 to 84. This has not been easy. Nature's raw petroleum, as you are all aware, actually has only a limited proportion of gasoline in it—and very little of this is high octane material. We have therefore had to improve on nature—to find ways to tailor-make gasoline far beyond the amount and quality in the crude oil.

The first major move in octane improvement and one in which our company played an important part—was the development of tetraethyl lead as an antiknock additive to gasoline. But there are limits to what tetraethyl lead will do. It cannot be added indefinitely. The nature of the base gasoline stock is very important—both in quality and quantity. To make really good gasoline in large amounts, you have to begin with good base stock, and then make it better. Intensive research was necessary to produce the proper base stocks in necessary amounts to deliver today's motor fuel.

Twenty years ago thermal cracking was already being practiced for the manufacture of gasoline. By cracking, gasoline could be produced in amounts greater than naturally found in the crude oil. Thermal cracking was followed by catalytic cracking, which came into the picture about 1937. Catalytic cracking produced a much higher octane gasoline than could be made by thermal cracking alone. Today the industry makes close to 40 per cent gasoline from crude oil—about twice the natural content—and we could easily make 80 per cent if the other products were not also needed.

The catalytic cracking process now most widely used is one known as the fluid cracking process. The Standard Oil Development Company played a major part in the creation of this advanced method of high octane gasoline manufacture. Fluid catalytic cracking, incidentally, supplied the major portion of war time aviation gasoline. And the basic feature—known as the fluidized solids technique —has since been recognized as useful far beyond oil cracking. It is today under study for application in many other industries as a fundamental advance in the handling of solid materials.

As we look ahead, we expect that the compression ratios of spark-ignition engines will increase still further. and that the oil industry will be called upon to provide still higher octane gasoline to operate those engines. In fact, at least one of the automobile manufacturers is quite definitely in a position to increase markedly the compression ratios of its cars, and it is likely that other car makers will do the same.

To the automobile user, this change will mean better mileage for the same performance. An automobile with a compression ratio of 10 to 1, for example, should average about 30 per cent more miles per gallon than present 6.7 to 1 engines.

Of course, a higher octane gasoline is required for the 10 to 1 compression ratio cars. It may be in the region of 97 or possibly higher. Petroleum research has developed the basic processes for producing gasoline of such a high octane number in large volume. Time and huge capital investments are required, however, to make such a large improvement in gasoline octane number. For this reason, increase in the compression ratio of automotive engines must not proceed at too rapid

*Presented at a meeting of the Department of Standards and Tests and the Department of Manufacture of the National Petroleum Association at the Esso Research Center, June 2, 1949.

†Esso Laboratories, Standard Oil Development Company.

a rate, and should be carried out in steps. It is our belief that a reasonable rate of increase in the compression ratio of automotive engines is basically sound. The companies associated with the Standard Oil Company (New Jersey) expect to provide gasoline that will meet our share of the needs of such a program.

Similarly, the advances in aviation have largely been made possible by the advances in fuel manufacturing techniques. The commercial development of iso-octane, followed by the different polymerization techniques, alkylation, etc., which made possible the large scale availability of 100 octane number aviation gasolines during World War 2, all provided impetus to the amazing developments in reciprocating aviation engines that we have observed during the last 15 years.

It is doubtful, however, if large further improvements will be made in the octane number of aviation gasoline. Although undoubtedly some changes in reciprocal engines will be made, and certain modifications such as the compound engines may come along, it is improbable that these will significantly affect fuel requirements. Present aircraft development is largely on planes that are propelled by jets or gas turbines. The fuel requirements for such equipment may be low O.N. gasoline, kerosine, or other cuts.

Hand-in-hand with fuel improvements have come improvements in lubricating oils. These have often been overlooked in the glamorous light of gasoline improvement. For ease of starting under cold weather conditions, a motor oil is required that has a low viscosity. To obtain low oil consumption, on the other hand, the lubricating oil used should have a reasonably high viscosity at engine temperature. These two requirements are obviously conflicting because oils increase in viscosity with decreasing temperature. What is needed to most nearly satisfy both, is an oil with minimum viscosity change with temperature. Twenty years ago we were entirely dependent on crude source for this important property. Today, however, this is no longer the case.

Perhaps the biggest single development that brought about this change was that of solvent extraction processes for producing, from a wide variety of crude oils, lubricating oils having lesser change in viscosity with temperature. In addition to improving the temperature-viscosity relationship, the solvent extraction process removes from the crude lubricating oils those materials that are responsible to a large degree for sludge formation, and as a result it is today possible to produce superior quality lubricating oils from many different crudes. From the standpoint of assuring an adequate national supply of high quality lubricating oils, the development of the solvent extraction process was of basic importance.

Another and, in some respects, equally significant development in lubricating oil research is the use of additives. One of the first of such additives was Paraflow, a material that has the effect of reducing the temperature at which the oil would gel—that is, congeal—in cold weather. This additive has been useful in two ways; one being to produce oils of very low congealing temperature, and the other to decrease the cost of wax removal where oils of very low congealing temperature are not required.

A number of other additives have since been introduced. Some reduce the effect of temperature on oil viscosity, others inhibit the oxidation of oils or disperse sludge and reduce varnish formation in the engine. The latter types are particularly useful for diesel engines and for heavy duty service in spark-ignition engines in trucks and buses.

What the future will bring in improved lubricating oils is difficult to say. There are, however, prospects for motor oils that will give still greater

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Comparative cost charts are available upon request.

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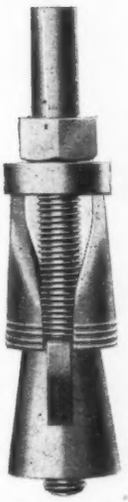

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improvement in engine condition and that will have such excellent viscosity temperature properties as to reduce the number of viscosity grades needed in any given marketing area.

As you are well aware, the oil industry also produces a large number of special oils for various industrial uses. These oils are extremely important, even though it some cases their volume is not large. Much research has been carried out on such special oils. As a matter of interest, I would like to mention a few examples.

Hydraulic mechanisms, which are increasingly used for power transmission of all types, require oils of as nearly uniform viscosity over wide temperature ranges as possible to minimize differences in performance. This is particularly true of aircraft mechanisms (automatic pilots, turret controls, landing gear actuators, and the like) and ordnance equipment such as fire control instruments and recoil mechanisms, where variations in actuating time would be very serious. Specially compounded petroleum oils have been developed that have the desired viscosity-temperature characteristics and these products, containing rust and oxidation inhibitors where needed, have an excellent record as aviation and ordnance hydraulic and recoil fluids.

The rapid growth in the use of automatic transmissions and torque converters in automotive equipment represents a somewhat parallel development, which should have a significant influence on the future lubricants situation. It has been estimated that the requirements for these oils may eventually be as great as 25 per cent of the motor oil requirements. This represents a new field about which not too much is yet known. However, such qualities as VI, stability, freedom from foaming, etc. will undoubtedly be important considerations.

Another example is concerned with the use of oil for protective coatings, particularly to prevent rusting. The rusting of iron and steel articles is an extremely serious economic problem. During the early war years, millions of dollars and much time were lost because of the rusting of close-tolerance aircraft engine parts, even during manufacture. Finished engines frequently became inoperative due to rusting, before they could be placed in service. Preservative oils containing powerful rust inhibiting agents were developed to protect parts during processing and shipping. In addition, special products were introduced that have the property of actually displacing water or perspiration from metal, thereby eliminating "finger printing", a serious source of machine shop rusting. Petroleum rust preventives are today in widespread use and have greatly minimized the corrosion problem, an invisible but highly important contribution to our over-all economy.

Another example is concerned with the textile industry. Wool fibers deteriorate when spun or woven in the absence of lubricants. Conventional mineral oils cannot be used as lubricants because they cannot be cleanly removed from the cloth by the mild scouring methods suitable for use on wool. While fatty oils, such as olive oil, are quite excellent in all respects, their short supply and excessive cost are serious disadvantages. Through research, petroleum oils have been developed which not only are readily removable from the finished cloth, but markedly lower the production cost of woolen goods. Again a definite gain from petroleum research.

There can be no doubt that continued progress in the field of liquid fuels and lubricants for every need from jets to sewing machines will come out of the industry's laboratories. But perhaps the most unique future developments of petroleum research, at least to the chemist, will

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Above photo—An actual Whitmor office building in Andrews County, Texas.

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come in the greatly expanded use of petroleum as a chemical raw material. Over the past decade, really startling research results have come about in this field, and oil is more and more coming to be a basic raw material for this country's rapidly growing synthetic organic chemical industry.

Petroleum molecules, of course, are composed largely of carbon and hydrogen, two of nature's most widespread building blocks, and research findings in the laboratories of both the petroleum and chemical industries, have developed means of making use of petroleum as a convenient and low cost source of these elements.

The original developments in producing chemicals from petroleum were concerned with the production of alcohols such as isopropyl, butyl, and amyl alcohol. The use of petroleum as a raw material for chemicals has now spread widely—among the chemicals are ethyl alcohol, ethylene glycol, aromatics such as toluene, various plastics, rayon and other fibers, fertilizers and so on through a long list, reaching even into fingernail polish and deodorants.

A very new chemical development, which was announced only last fall, is the commercial production of iso-octyl alcohol from petroleum. The first plant was at that time placed in operation at Esso Standard's Baton Rouge refinery. This new chemical will be highly useful, among other things, in combination with phthalic anhydride, also being made from petroleum, as a plasticizer for resins. The basic technique that has been developed for making iso-octyl alcohol may have extensive application to making chemicals required in the manufacture of certain synthetic fibers and various resins, as well as detergents and many other materials.

One really vital chemical produced from petroleum is butadiene, the main raw material for synthetic rubber. The World War II program, as finally worked up by the office of the rubber coordinator, involved production of 65 per cent of the butadiene from petroleum. Today, essentially all butadiene used for synthetic rubber is produced from petroleum, as it is possible to furnish the butadiene at a much lower cost from this material than from the nearest alternative, ethyl or grain alcohol.

Our research in the rubber field also developed an entirely new type of synthetic rubber known as Butyl. This synthetic rubber was widely used during the war, and is today being used for production of inner tubes. It is likely that many or all of you here tonight are using Butyl inner tubes in your cars. You may have noticed that

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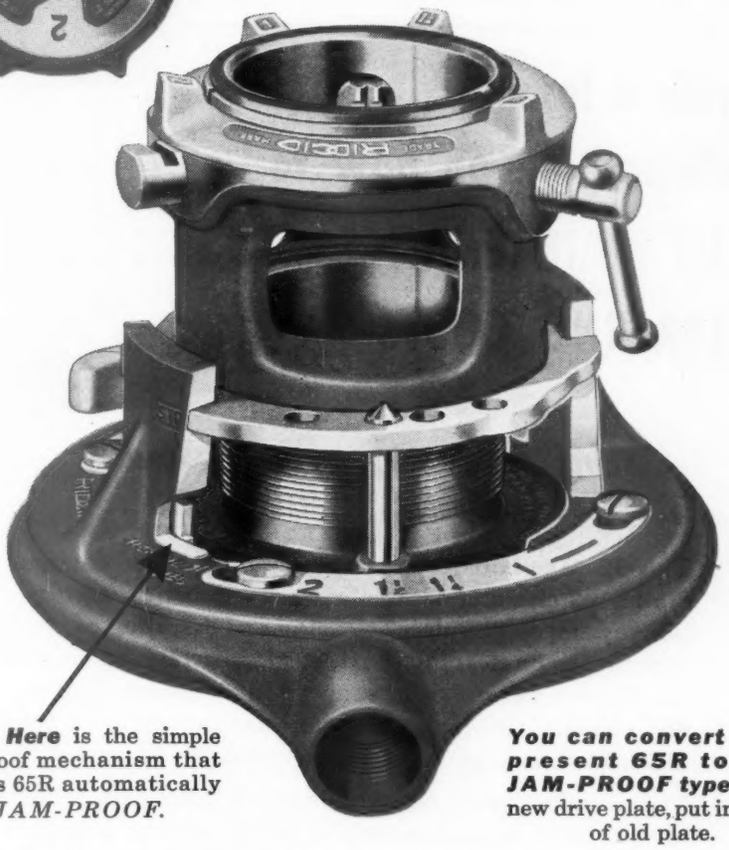

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you have to put air in your tires much less frequently now than before the war. This is due to the fact that Butyl holds air about 10 times as well as natural rubber.

While the use of petroleum as a chemical raw material is rapidly expanding—today some five or six times as much is so used as before the war — the total amount is but a minor factor of the over-all petroleum supply, a little less than 1 per cent of the total petroleum and natural gas production.

The picture of people's ever expanding needs for petroleum in one form or another raises a question as to ultimate exhaustion of the resource. The oil industry has recognized for a long time that, with growing consumption of oil products, some day other materials than natural crude oil will have to be utilized. For more than 20 years it has done a great deal of work on production of oil products from other raw materials such as coal, oil shale and natural gas. Last year, for example, it is estimated that more than $10,000,000 was spent for such research.

During this 20-year period, we of the Jersey Standard group alone, have spent more than $20,000,000 on such problems, approximately half being on the hydrogenation process, both as applied to producing higher yields of light products from crude oil, and as applied to production of oil products from coal, and half on the conversion of coal and natural gas to oil products by processes such as the Fischer-Tropsch process. In addition, large oil hydrogenation plants were erected at a cost of $16,000,000 and operated for a number of years.

Work on the Fischer-Tropsch process was begun just before the war, but discontinued under the press of more immediate problems. Since the war, this project has again been picked up by ourselves and others in the industry. Some very real improvements have been made, and it is now felt that a basic process for converting either coal or natural gas into oil products has been pretty well worked out, although there still remains some work to be done, particularly on coal. A considerable amount of work has also been carried out on the conversion of oil shale into oil products.

No one can predict accurately when it is going to be necessary to turn from crude oil to other raw materials to augment natural oil supplies. Due to the recent high rate of discovery of crude oil, both outside and inside the United States, it does not at present look as though it will be necessary to rely on raw materials other than crude oil for a considerable period ahead.

But the industry's research laboratories have already given us the necessary tools to assure that we will be ready to turn to other materials for producing oil products when the need arises. These materials exist in amounts sufficient to carry the nation's present oil needs for a great many years. And new sources of energy will surely come to use—atomic power, for example, is anticipated within a generation —to help carry the burden of supplying civilization's over-all energy needs.

It seems obvious that as far reaching as have been the past developments in the petroleum industry, there will be many new and equally important developments in the future. What they will be is not exactly predictable, although we have tried to indicate some of the possible trends in the presentation. In any event, we may expect that the various research and technical organizations in the industry will continue along the road of progress on which they are already traveling, and that in accordance with past performance they will contribute through their developments to ever increasing standards of living for everyone. We in the Standard Oil Development Company are looking forward optimistically to contributing our share to this progress. * * *

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